

# NIGHTFALL

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ASTRONOMICAL SOCIETY OF SOUTHERN AFRICA



**Vol. 3 No. 2**  
**April 2019**

# Technical data for this issue's Sh2-308 "Dolphin's Head" image

**Astrophotographer:** Martin Heigan

**Object:** Sharpless 308 (the Dolphin Nebula), narrowband H $\alpha$  Palette image of the faint emission nebula also cataloged as Sh2-308, RCW 11, and LBN 1052.

**Object type:** [Wolf-Rayet gas-ejection emission nebula and HII region](#) surrounding the 7th magnitude (visual) star HD 50896, also known as the variable star EZ Canis Majoris, located at RA 06 54 13 Dec -23 55 42. It is presently classified as a WN4b spectral type transitioning from a  $\pm 40 M_{\odot}$  blue

supergiant  $\Rightarrow$  Wolf-Rayet  $\Rightarrow$  Luminous Blue Variable (LBV). The star is located about  $8^{\circ}$  south of the night sky's brightest star Sirius. The Wolf-Rayet  $\Rightarrow$  LBV stage is the last stage a high-mass  $40 M_{\odot}$  star

undergoes before sudden core collapse and Type II supernova detonation. The delicate bubble-like nebula shown here is the surface shell and near-surface layers composed largely of hydrogen of gas with trace amount of doubly-ionised oxygen (denoted OIII).

This image is the result of photographing over several nights from dark rural skies near my home. Diaphanous gas ejection shells like this push the limits of my modest 71 mm f/4.9 telescope and imaging gear.

## Technical Info:

24 x 600 sec. 7nm Hydrogen-Alpha (H $\alpha$ )

24 x 600 sec. 6.5nm Doubly Ionized Oxygen (OIII)

William Optics Star 71 mm f/4.9 Imaging APO Refractor.

QHY163M camera sensor cooled to  $-15^{\circ}\text{C}$ .

Calibration frames: Bias, Darks and Flats.

SGP Mosaic and Framing Wizard.

Astrometry.net ANSVR Solver via SGP.

Pre-Processing and Linear workflow in PixInsight.

Finished in Photoshop.

## Astrometry Info:

Center RA, Dec: 103.602, -23.925

Center RA, hms: 06h 54m 24.409s

Center Dec, dms:  $-23^{\circ} 55' 29.074''$

Size: 1.48 x 1.11 deg

Radius: 0.925 deg

Pixel scale: 3.33 arcsec/pixel

Orientation: Up is 113 degrees E of N

[View an Annotated Sky Chart for this image.](#)

[View this image in the WorldWideTelescope.](#)

# NIGHTFALL

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Urania, the Muse of Astronomy and the Heavens, found on the interior of a temple wall in Pompeii, amazingly intact after two millennia.

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 Montibus (catena Mun-  
 tribus, in hoc

Observata in 27 Grædâ & ten una App- quæ  
 G. D. A. 1683.  
 Anno Christi 1643. Die 2 Decemb. hora 4 i. med. post. mer.  
 et Oppositione veri 11. Die 7 Current.



Scalping

Moon in waning gibbous phase from Johannes Hevelius Selenographia, 1687. See story on page XX.

[Original image & data here.](#)





# Martin Heigan's Vela SNR in H $\alpha$ and OIII

The limiting magnitude of a Telescope is important for visual observation, but a Telescope is able to capture much fainter Deep Sky Objects with long exposures and sensitive CCD and CMOS cameras. With a fast Astrograph and camera, one is able to capture incredible detail on modest equipment. Narrowband filters and cooled Monochrome cameras further enhance the possibilities, as it eliminates light pollution issues. Polar alignment and AutoGuiding becomes even more critical with long exposures, and there is no substitute for capturing enough data. Astrometry Plate Solving allows one to capture a target over several sessions, which is needed when you go after faint targets, or need to capture a mosaic due to the size of the object. Calibration frames are essential to allow one to extract the signal from the noise during image processing.

= *Martin Heigan*

Full-resolution of Martin's Vela SN image is *available on his Flickr page*.

**Image data:** wide-field Narrowband HOO Palette (R=Ha, G=OIII, B=OIII) mosaic of a portion of the the huge Vela Supernova Remnant (also known as Vela XYZ; Gum 16; SNR G263.9-03.3; 1E 0840.0-4430; RE J083854-430902).

This mosaic was photographed over a month, during several sessions. Deep Sky Objects like this is always a challenge, as it is time-consuming and pushes the limits of my Telescope gear. It's rewarding when you have to work hard for an image, and wide-field mosaics are always fun to image and process. This is an example of how interesting the rarely seen, faint and massive wide-field Deep Sky Objects are.

### Technical Info:

4 Panel wide-field Mosaic.  
Lights/Subs total integration time: 32 hours.  
24 x 600 sec. 7nm Hydrogen-Alpha (Ha) per panel.  
24 x 600 sec. 6.5nm Doubly Ionized Oxygen (OIII) per panel.  
William Optics Star 71 mm f/4.9 Imaging APO Refractor.  
Sensor cooled to -20°C on my QHY163M.  
Calibration frames: Bias, Darks and Flats.  
SGP Mosaic and Framing Wizard.  
PlaneWave PlateSolve 2 via SGP.  
Pre-Processing and Linear workflow in PixInsight and finished in Photoshop.

### Astrometry Info:

Center RA, Dec: 127.504, -44.923  
Center RA, hms: 08h 30m 00.880s  
Center Dec, dms: -44° 55' 23.969"  
Size: 3.43 x 2.08 deg  
Radius: 2.006 deg  
Pixel scale: 7.73 arcsec/pixel  
Orientation: Up is 301 degrees E of N

If you want to imagine what life is like inside a supernova at the moment it explodes, [watch this](#) and then go watch a boiling pan of water and think of it as spherical.



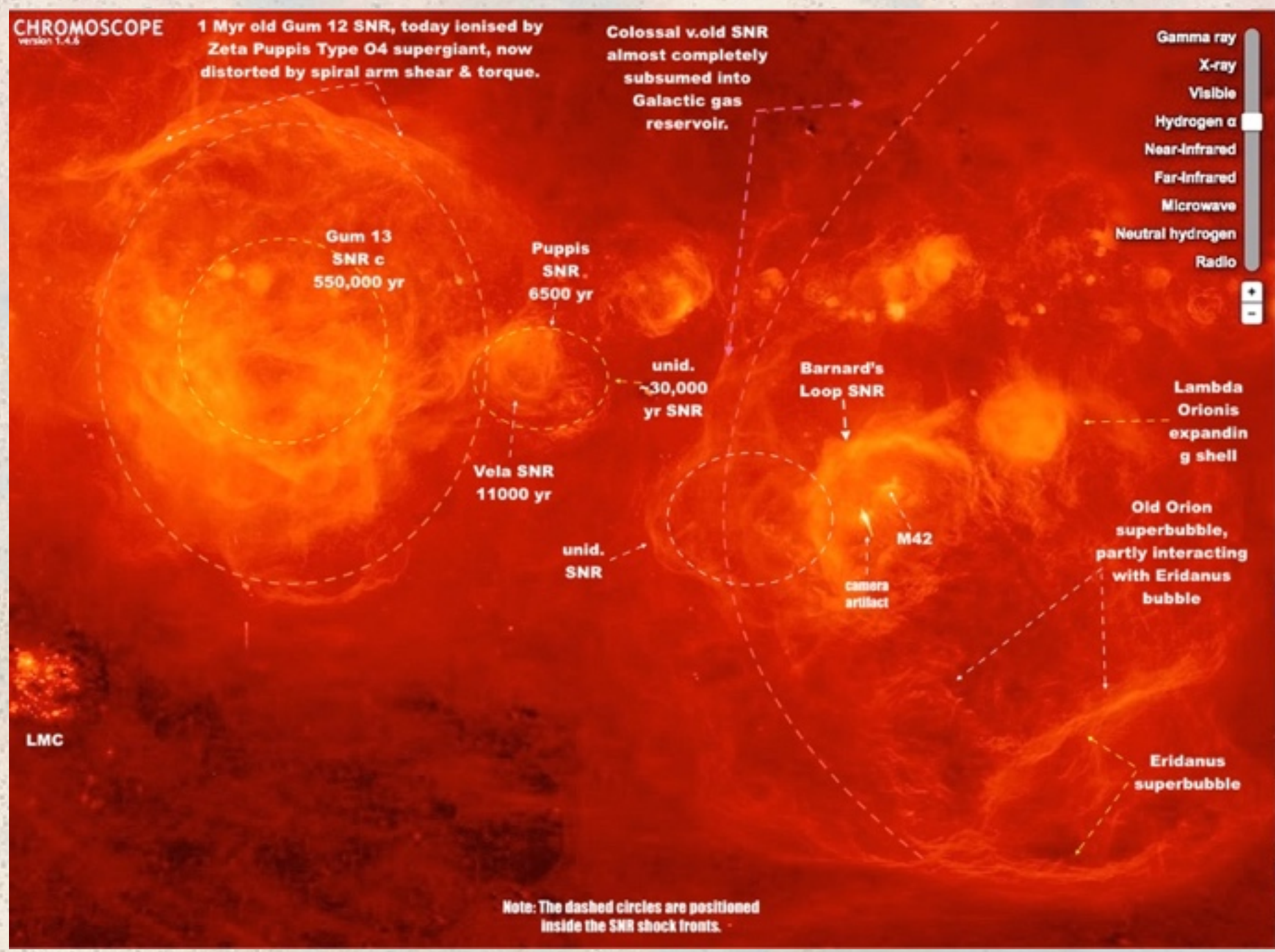
**Location of the Vela pulsar on Martin Heigan's image. In reality, the Vela pulsar would not be visible in his image; it emits mainly in the X-ray band. The association of the Vela supernova remnant with the Vela pulsar was discovered by astronomers at the University of Sydney in 1968.**



# The Vela SNR's exotic neighbourhood

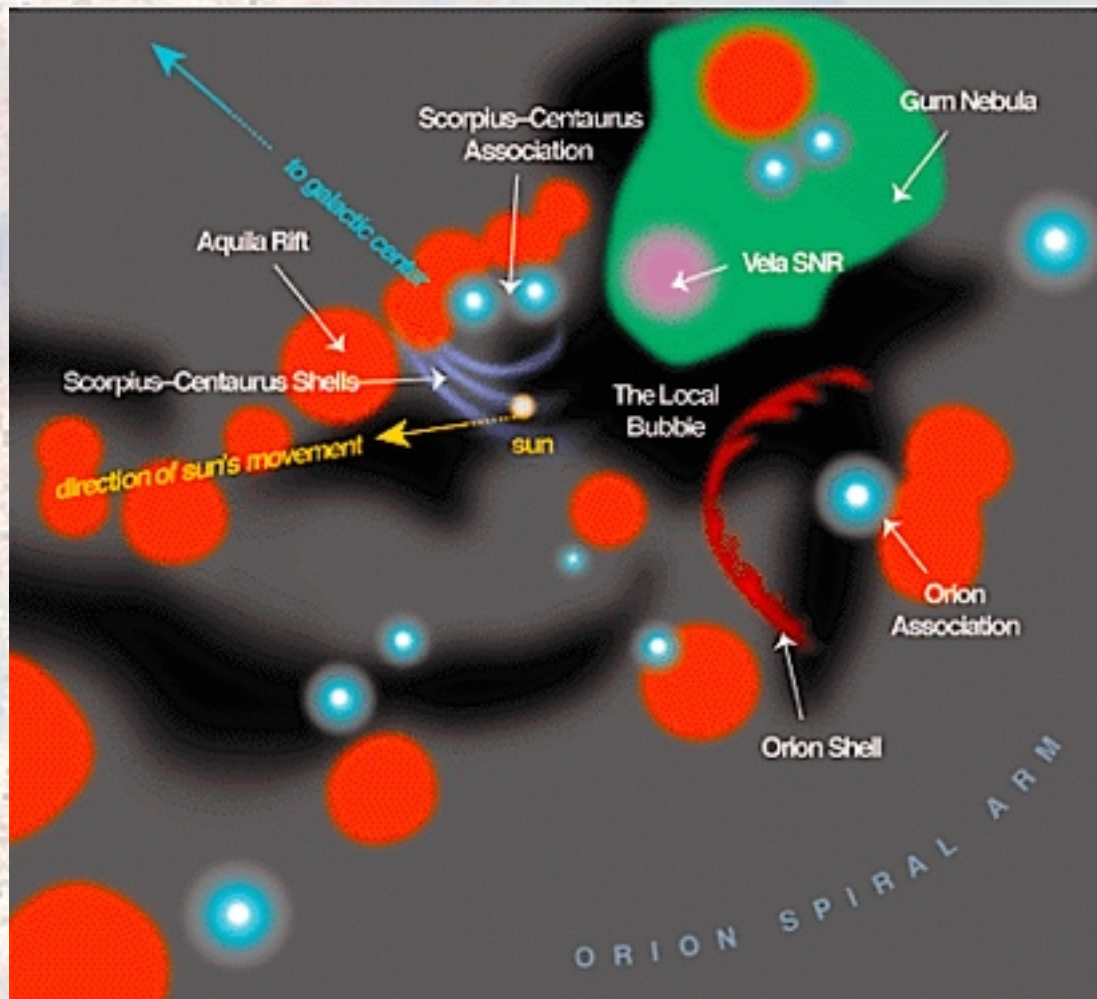


Named for the cosmic cloud hunting Australian astronomer Colin Stanley Gum (1924-1960), The Gum Nebula is so large and close it is actually hard to see. We are only about 450 light-years from the front edge and 1,500 light-years from the back edge. Covered in this 40+ degree-wide monochrome mosaic of Hydrogen-alpha images, the complex nebula is thought to be a supernova remnant over a million years old. Today it sprawls across the now obsolete Argo Navis, the Cosmic Ship in the Sky. This image embraces the southern constellations Vela the Sails) and Puppis (the afterdeck). This spectacular wide field view also explores many objects embedded in The Gum Nebula, including the younger Vela supernova remnant and the Puppis supernova remnant. The image is a crop from a 111-tile hydrogen alpha mosaic imaged remotely from Coonabarabran, NSW. See the detailed annotations on the next page. *Image by John Gleason.*

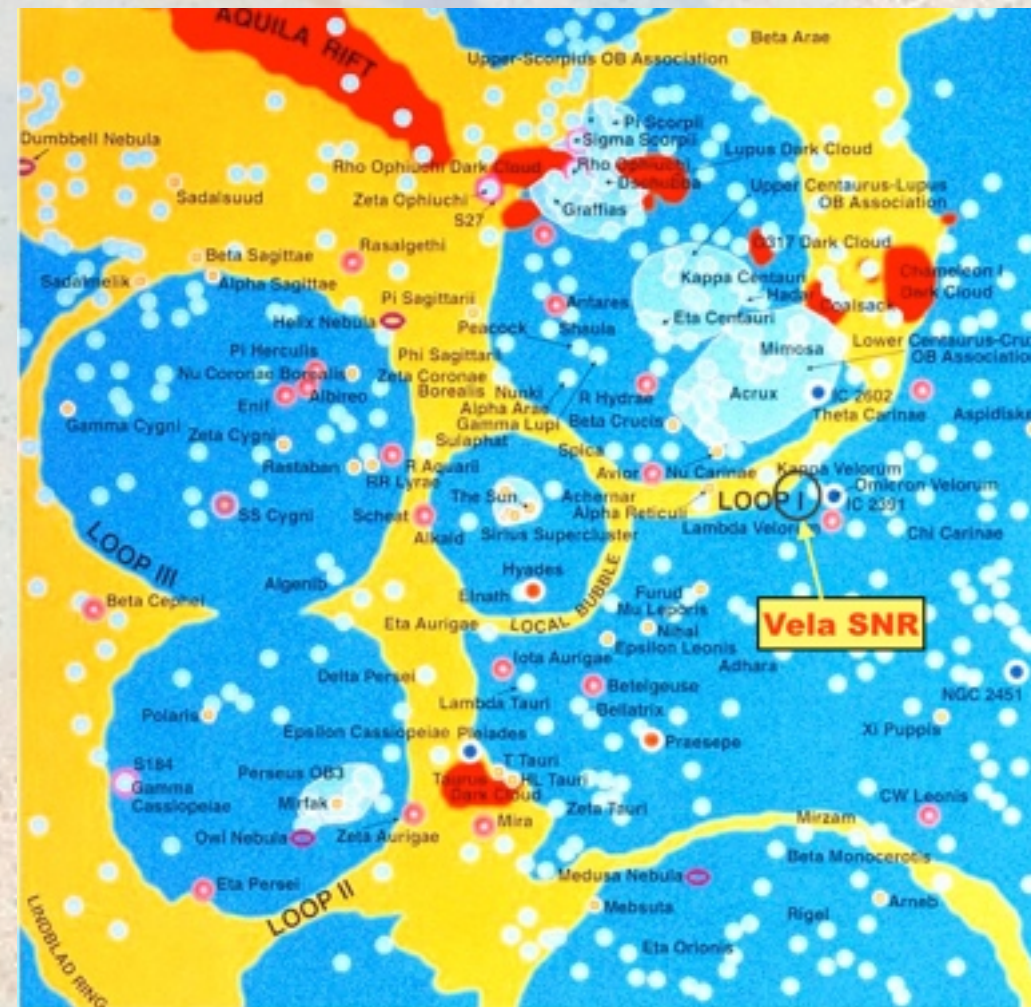


The region around the Vela SNR is a sizzly neighbourhood. Hydrogen alpha emits its characteristic reddish radiation at from 11,000 to 36,000 K. In supernova remnants the temperature rises to more than 1 million K.

The Gum 12 Nebula in the upper left is an immense, tenuous, diffuse ancient supernova remnant, the largest in the entire celestial vault. It is invisible in the optical bands, but breathtaking in Ha, neutral hydrogen, and far IR. Its centre located about 450 parsecs from the solar system, the fading wisps of the last dissipating remnants left over after one or more supernovae 1 to 3 million years ago. Gum 12 is one of the largest SN remnants known within the Milky Way and an important study in the extent and age an expanding supernova bubble propagating outward from supernova explosions within the galactic arm. That includes interactions between the supernova blast wave and molecular clouds. instances are known when a passing supernova shock induced cloud-collision star formation on the leading edges of the shock front.



Location of the Vela SNR, Gum Nebula, Orion Shells, Sco-Centaurus stellar association, and Aquila Rift, all within the Orion Spur, which partially bridges the Sagittarius–Carina Arm and the Perseus Arm. Currently, the Sun is passing through a Local Interstellar Cloud (LIC) shown in violet, which is flowing away from the Scorpius-Centaurus Association of young stars. The LIC resides in a low-density hole in the interstellar medium (ISM) called the Local Bubble, shown in black. The Gum 12 Nebula in green is a region of hot ionized hydrogen gas. Inside the Gum Nebula is the Vela Supernova Remnant shown in pink, which is expanding to create fragmented shells of material like the LIC. Graphic by Linda Huff and Priscilla Frisch, [APOD 17 Feb 2002](#).



This plot of the Vela SNR location is rotated 45° clockwise from the Frisch plot on the left. The Vela SNR has been added above. The complexity of the local environment that we see in the night as a vast panoply of beautiful glitter is actually a very slowly boiling Galactic tea kettle, filled with hot surfaces inside which are cool bubbles. Instead of rising to the surface, though, these are seething inside their own teacup. The Galactic disc is filled with regions like this. It is indeed a wonder that anything so fragile and fleeting as life can occur anywhere in this maelstrom.

Supernova remnants are not simply thin bubbles that get bigger. During the violent moments before the star's explosion, its core was a seething, writhing, gyrating mass so fissile and unstable it barely held itself together. [This simulation](#) shows about 10 seconds of life in a collapsing-core interior before the whole thing is blown away in a rebound from the extreme densities of a catastrophic collapse.

The upper layers are not blown out in a nice sphere of atoms and ions. There is a lot of free atomic gas, but there also uncountable multitudes of shreds and blobs that retain the chemical identity of where they were inside the star when it disrupted. Some of the blobs were originally deep inside the star, even next to the nuclear core. As the blobs hurl into space, they distend, writhe, spread. Moreover, the thin space into which they fly is not evenly spread; space is filled with atomic and molecular clouds. The molecular clouds are thin—10 to 100 atoms per cubic centimetre, but they make up for it in size—50 to 300 light year diameter. “Empty” space is also riven with compression fronts from turbulent shocks that propagate incessantly in a spiral arm disc due to the shear and torque forces in the rotating disc. Flying through a supernova blast wave is like flying through a hail storm with tennis-ball sized stones.

Within a few hundred years the blobs of progenitor gas distend and spread out into an irregular and clumpy medium. Bubble-like shells and writhing streamers evolve. Most young supernovae bubbles, e.g., the [Tycho SN in 1572](#), are still gravitationally contiguous enough that they retain their basic round shape. That coherent round shape is maintained for hundreds to thousands of years as the expanding bubble gains mass from the gas that it sweeps up before it. The rounded shape will slowly degrade as more and more gas is swept up, until the point where the supernova shell has accumulated about 10 times its own mass.

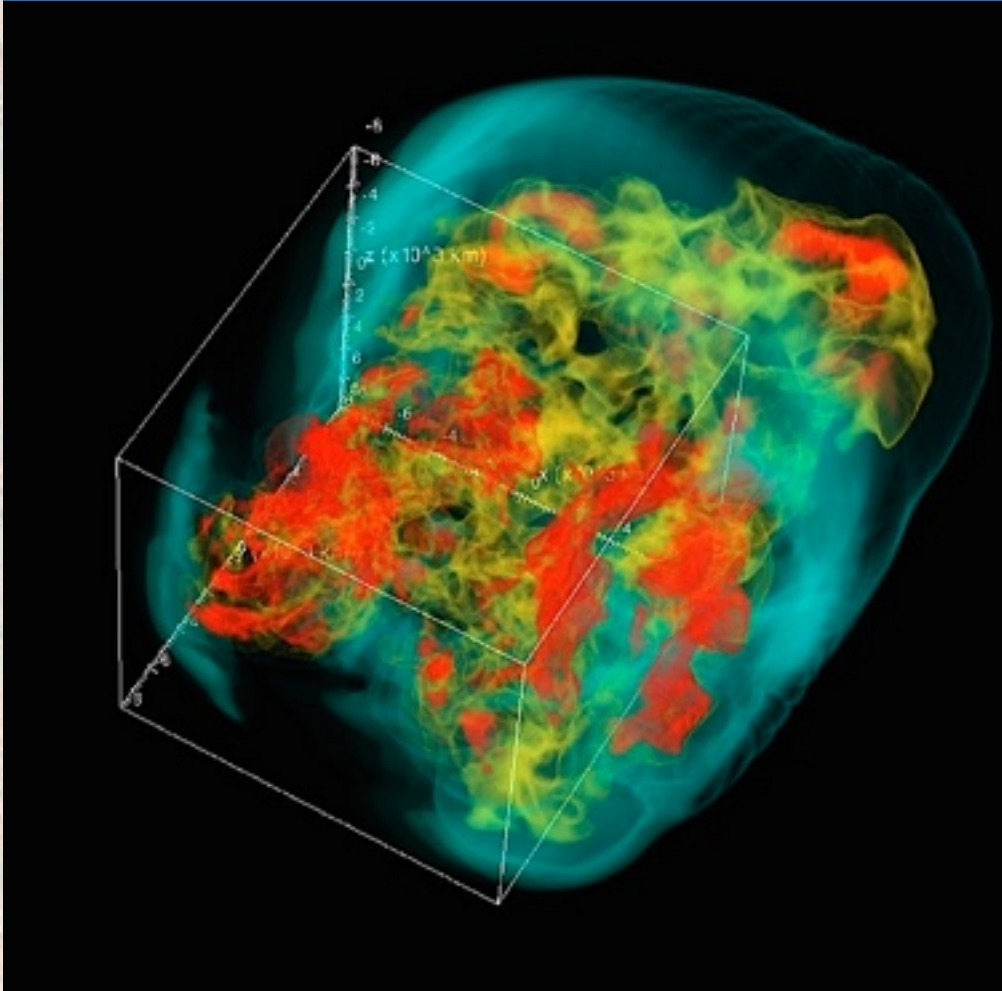
By ten thousand years the remnant has dispersed into the complex set of filaments, intersecting rings and filaments, and shards (e.g., the Pencil Nebula, which part of the Vela SNR). Each filament has its own local velocity, chemical composition, and vector toward which it is expanding. The slight differences in chemical composition from filament to filament trace back to the layers inside the progenitor star where the blob was hurled by the blast. Some blobs lob through space like cosmic shrapnel. Vela has at least five of these blobs which have held together 11,000 years.

A supernova shock wave is a messy overdense medium expanding into a messy underdense region in a giant spiral arm.

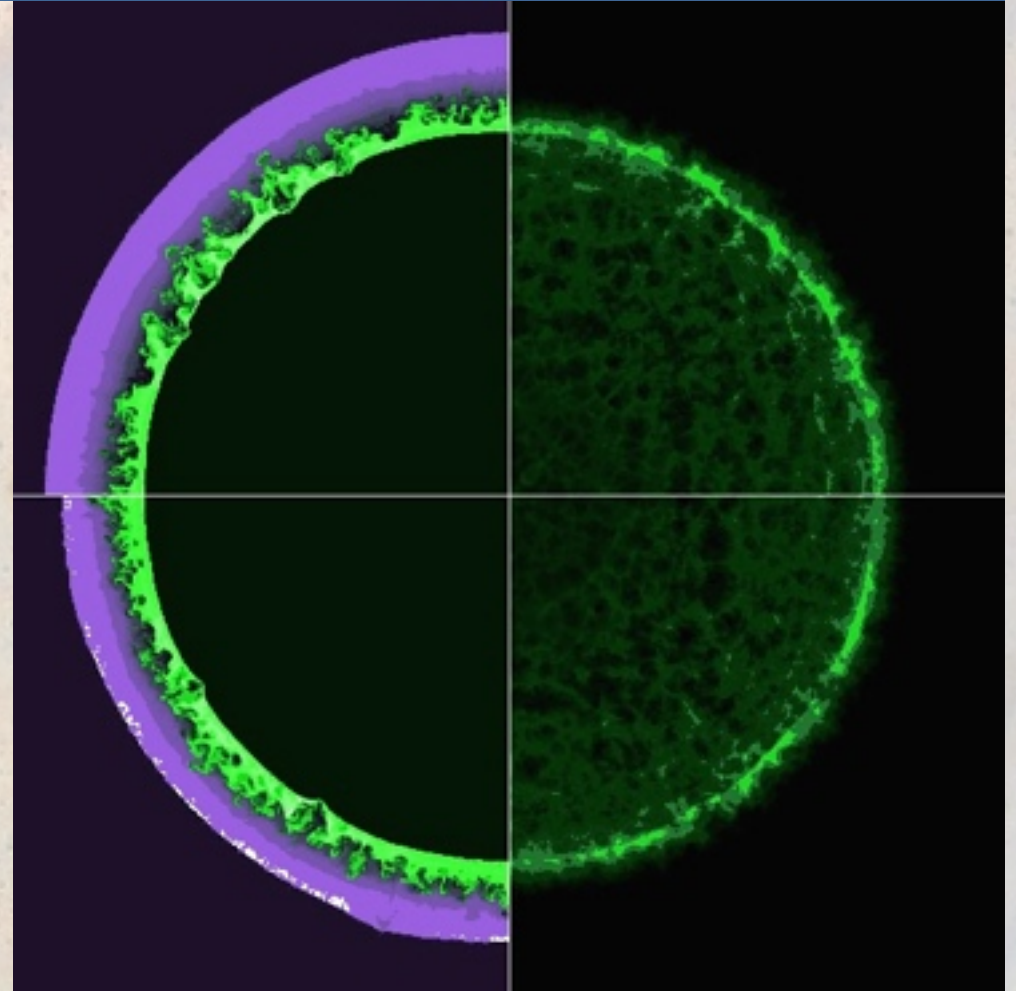


The Large Magellanic Cloud supernova 1987A two weeks after the initial explosion was first detected February 1987. The red-yellow ball of light recorded here records the rather small amount of energy that shows up in the visual bands. Far more energy is in the UV and X-ray bands emitted by gas propagating hypersonically (Mach as high as 1000) through the thin, cold interstellar gas. Since it is difficult to imagine how large this light patch was where it was actually expanding, David Malin of the AAU in Australia superimposed a negative photograph of the foreground stars on our side of the blast. The dots have been sized according to their diameters, red giants being the largest. The star which went supernova had been previously observed and catalogued as Sanduleak  $-69^{\circ}202$ . Photograph made from plates taken in March 1987. The image width is about 8 arc min. *Source: David Malin, Australian Astronomical Observatory.*

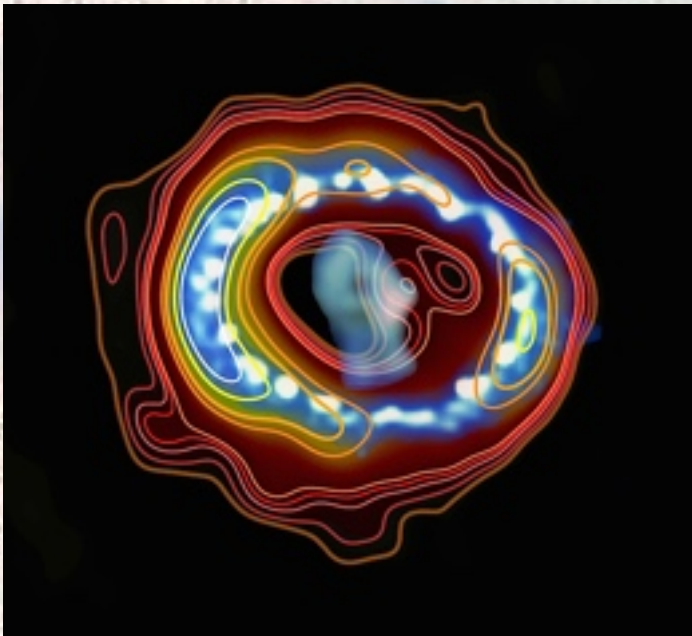
# Ancestral origin of the filaments and shells in Martin's image shortly after the explosion



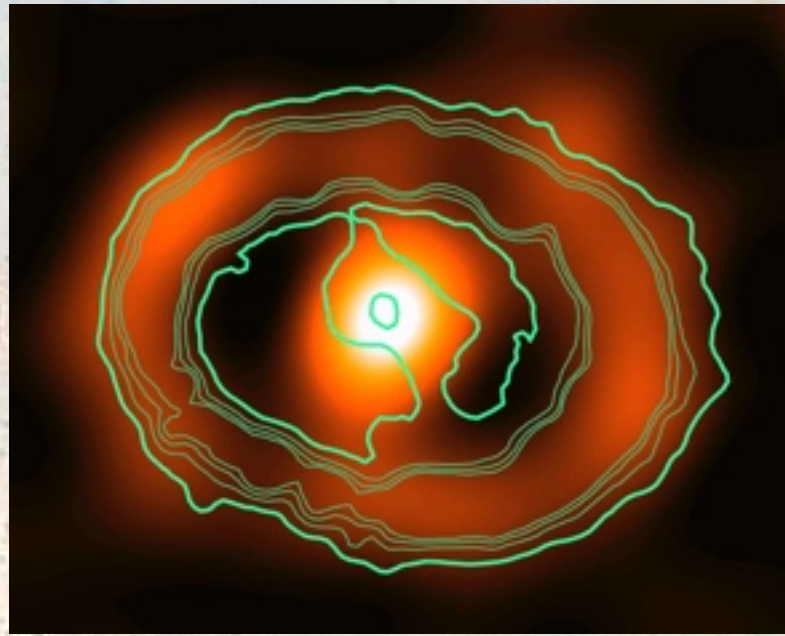
The highly chaotic, filamentary, bubble-like character of a supernova shock wave two seconds after the infalling mass of the initial core collapse has bounced off the surface of the neutron star. Already the key features of the late-phase supernova remnant have begun—filaments, bubbles, threads, high-density hot spots. This MHD simulation shows only the region around the core bounce in which the actual explosion has occurred. The thick envelope layers of the star surrounding this core will be shocked into clumps and threads during the ballistic explosion of the chaotic masses here.



Snapshot of the expanding supernova blast penetrating into the blissfully unaware outer envelope of the star. The writhing fingerlings of exploding gas shove violently into the envelope, forming [Rayleigh-Taylor instabilities](#) as they crash into the envelope gas (purple). Each of the volumes enclosed by the space between those fingerlings may retain enough internal gravitational coherence to end up a blob or filament flying into space. The fingerlings themselves are already a super-hot gas and will stay a gas as they move out into space. It is through this process that supernovae remnants acquire their blob-thread-gas structure that we see in images like Martin Heigan's.



HST image with graphic overlay showing the torus of radio emission in the SN1987a supernova in the Large Magellanic Cloud. Astronomers in Australia and Hong Kong assembled this image in 2013 to combine an overlay of radio emission (contours) with a Hubble Space Telescope image of the supernova (blue ring and bright spots). This image traces a compact source, a [pulsar wind nebula](#) called a [plerion](#), in the centre of the radio emission. The Crab Nebula is another plerion SNR. [Source: ICRAR Australia.](#)

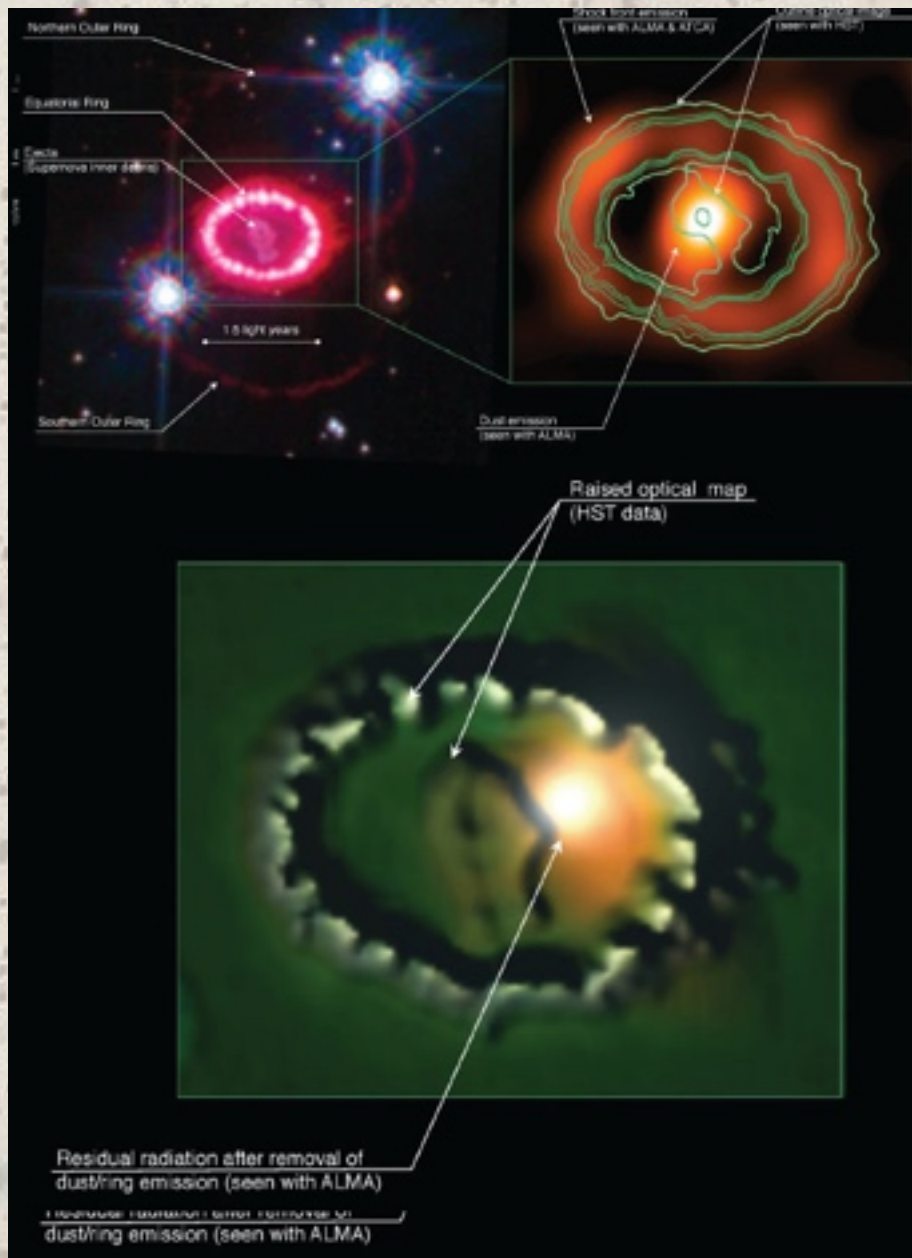


[YouTube of time-lapse video](#) showing the aftermath of the supernova SN 1987a in the LMC over a 25-year period from 1992 to 2017. The shockwave is exploding outward, slamming into pre-supernova debris that the star expelled in the seething, unstable years before the actual supernova blast.

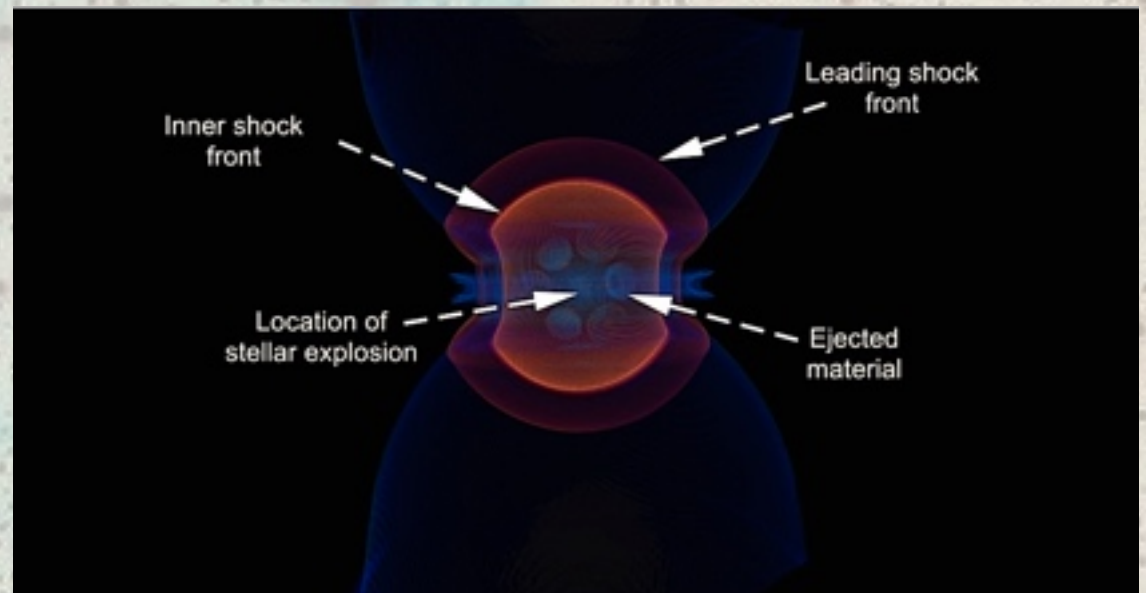


This image of the supernova remnant E0102 shows both X-rays (blue) and visible light (red and green). The faint X-ray source at the centre of the red ring is the neutron star progenitor of the supernova. The larger X-ray ring was known for a long time, but data from the ESO Very Large Telescope in Chile led to the discovery of the smaller ring, which emits visible light at a narrow range of red wavelengths. The green-emitting gas blobs on the outer periphery are the clumps of the star ejected during the supernova explosion which have retained their gravitational cohesion.

Before a supernova explodes like SN 1987a did, it goes through some death shudders. SN 1987a's progenitor star, Sanduleak -69 202 went through both a red and blue supergiant phase. During both these phases, it ejected material into concentric rings speeding away from the star. After a high-mass star passes through the red and blue supergiant phases, the star pauses in what is termed a Blue Loop. After this, it eventually goes supernova. It expels material at a much higher velocity than during its previous red and blue supergiant phases. The hypersonic-velocity supernova shock wave eventually overtakes the slower ejection gas and slams into it so fast that a rebound-wave builds up and moves backward toward the old progenitor star. Reverse shocks are very high energy and a the primary energy source for cosmic

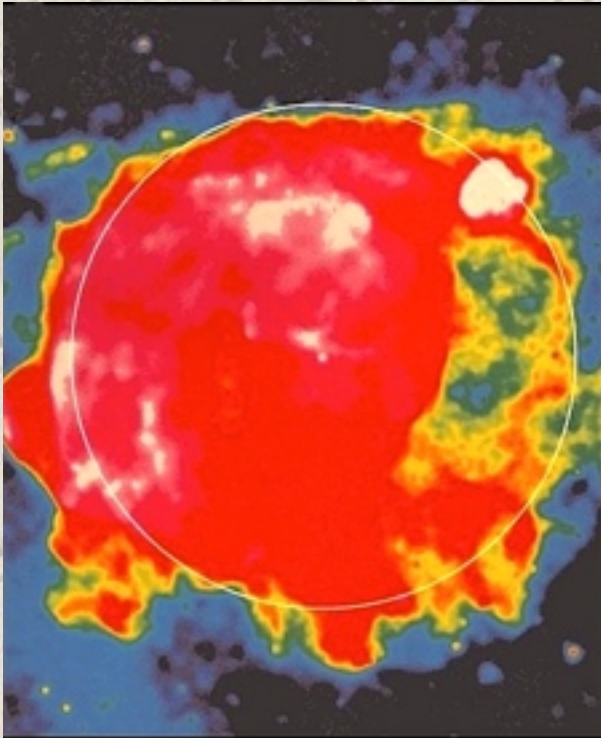


- **Upper left panel:** SNR1987A as seen by Hubble in 2010.
- **Upper right panel:** SNR1987A as seen by the Australia Telescope Compact Array and the Atacama Large Millimetre/submillimetre Array.
- **Bottom panel:** a computer generated visualisation of the remnant showing the possible location of a pulsar. The “diamond necklace” structure is caused by the blast wave hitting dust-rich gas clumps. Image credit: ATCA / ALMA / G. Zanardo et al / NASA / ESA / K. France, University of Colorado, Boulder / P. Challis and R. Kirshner, Harvard-Smithsonian Centre for Astrophysics.

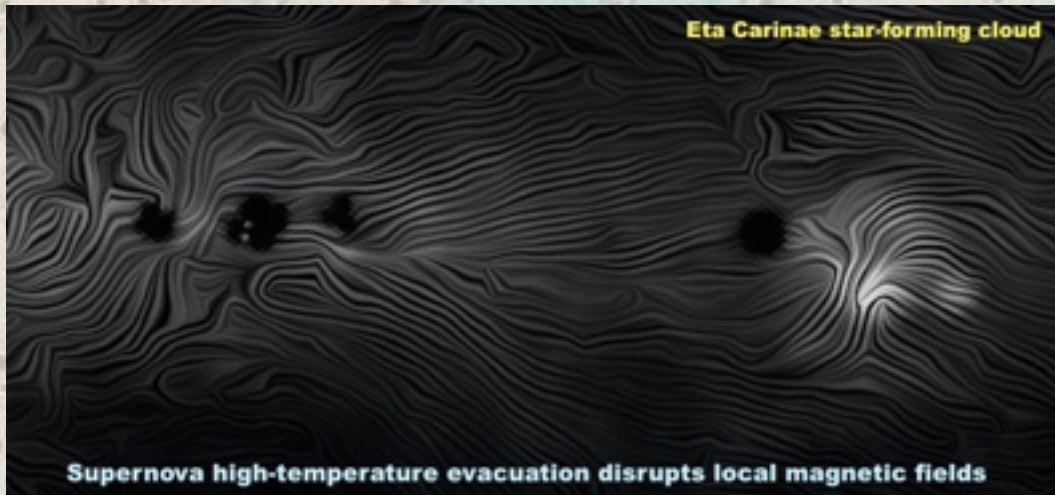
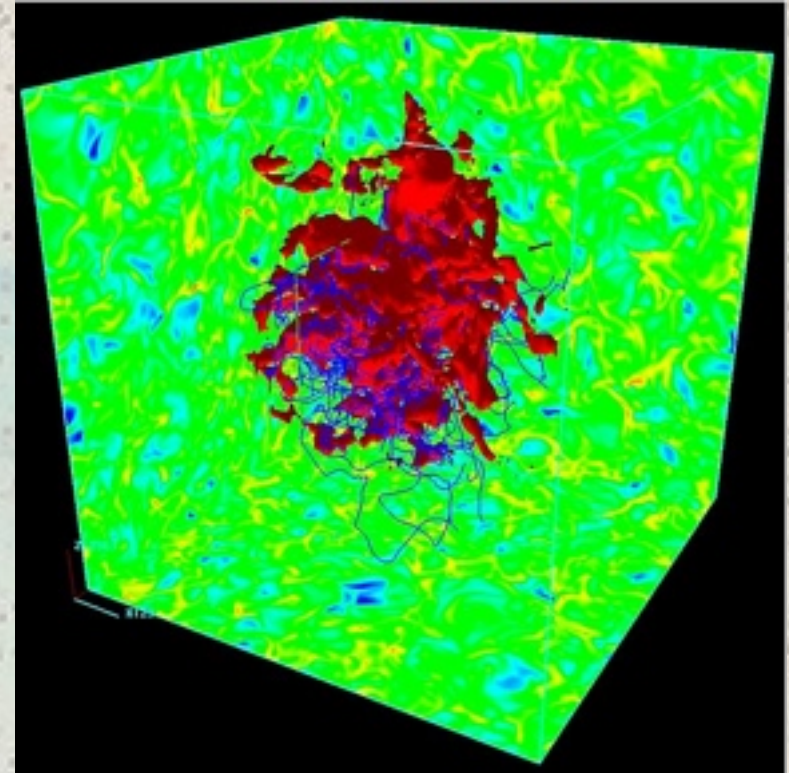


[Full-motion video of a three-dimensional simulation](#) of the development of SN 1987a between 1989 and 2014. The model shows that the SNR developed more strongly and rapidly on one side. Lopsided SNRs are not unusual. There are several reasons for lopsided SNR expansion shells—off centre detonation in the progenitor; the presence of a nearby binary companion; significant inhomogeneities in the surrounding interstellar medium. [See this ICRAR Australia web page for 163 more astronomy visualisations and lectures.](#)

The Vela SNR X-ray surface is still energetic enough to emit X-rays even after 11,000 years. Note the bubble morphology. The white spot in the upper right is the younger, hotter Puppis SNR, 4 times more distant than Vela. Source: [ROSAT/XMM Newton](#).



*Right:* Several milliseconds before the near-instantaneous collapse of the iron core into a neutron star, the regions shown in red are a seething cauldron of giant density bubbles writhing and intermingling so chaotically that it beggars verbal description. The net effect is to destroy the star's once-intense magnetic field (blue lines). Without the stabilising effects of a magnetic field, the exploding core is governed by the physics of density gradients in extreme gravity without the dampening, smoothing effects of a magnetic field. One effect is the ejection of giant blobs of matter that move ballistically, faster than the star's unbound gas.



Deep within the core of the pre-SN star, the intense writhing bubbles of extremely dense gas destroy the core's magnetic field. The now magnetically chaotic core expands with the rest of the envelope into the Galactic medium. By the time the bubble reaches the state shown in Martin's image, the tiny magnetic hole in the core of the star has blown a gigantic magnetic hole in the galaxy disc.

**Flying through a supernova remnant would be like flying through a hailstorm with tennis-ball sized stones.**

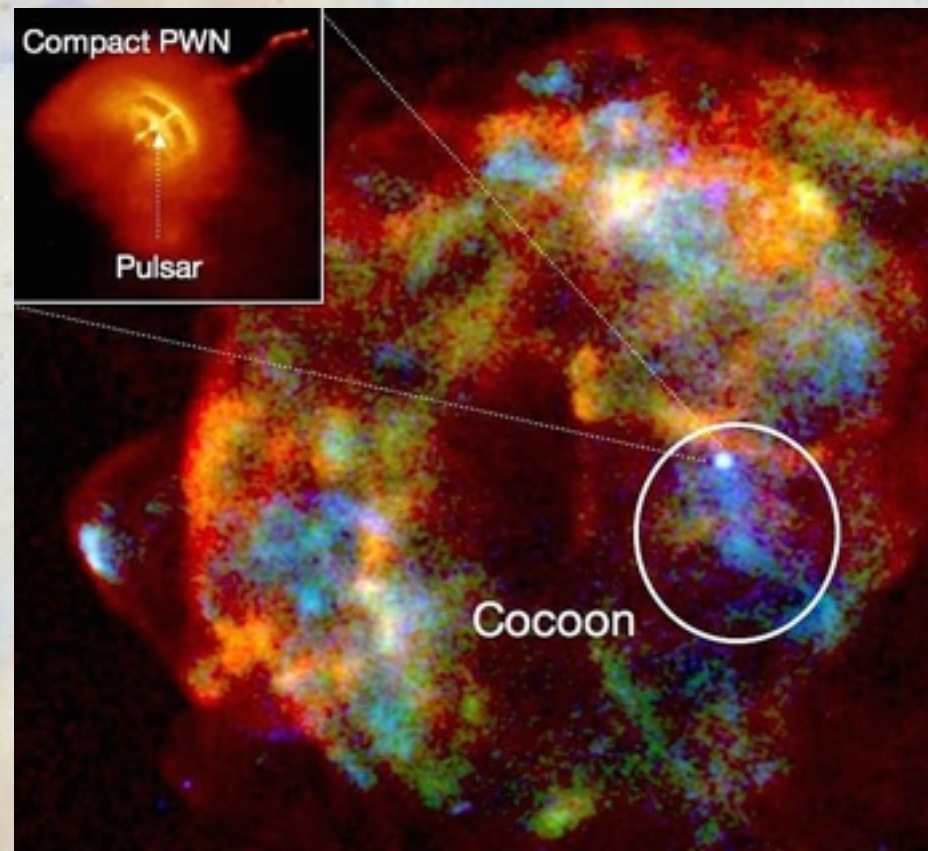


The Vela SNR was first examined as an X-ray source by researchers using the 1990s era ROSAT satellite, which was designed to survey the heavens in X-ray bands. In this image and the one on the previous page the surface of the X-ray emission is raggedly spherical, while images in the optical bands show a tattered patchwork of disrupted arcs expanding into the tenuous gas of the disc. The dramatically different appearances tell us much about the complex matrix of gas clouds that invisibly inhabit the disc plane of a spiral galaxy.

When a supernova detonates, for the first 100,000 to one million seconds (>1 day to 11 days) an extremely hot fireball of gas blasts out in all directions at hypersonic velocities as high as Mach 1000. The gas behaves like a fluid as it blows into the cold, thin interstellar medium (ISM). The ISM has typically fewer than 10 hydrogen atoms per cc and is a nippy 5–20 K. The expanding shock front flash-heats the ambient gas so much that it blazes in X-rays, though it is still too hot to emit in the optical band. It is still glowing in X-ray even now after ~11,000 years.

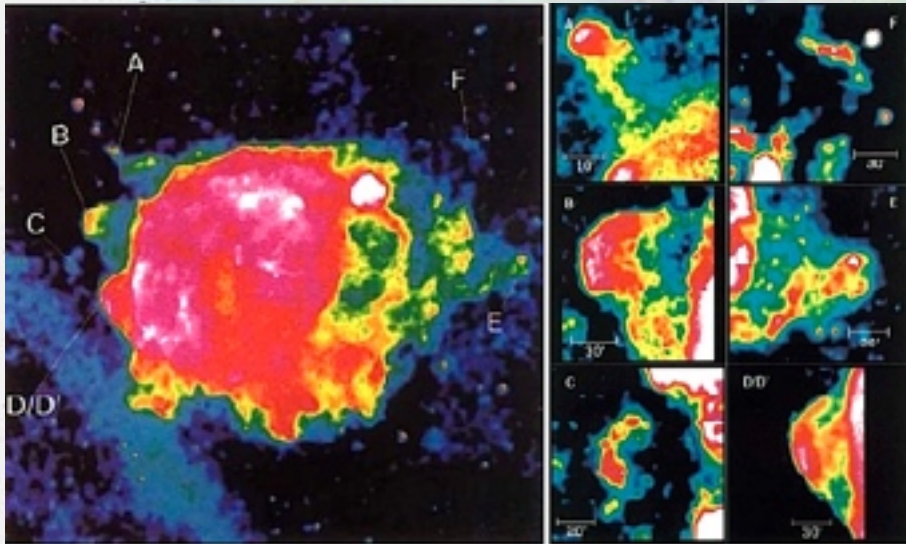
During the early days after the blast the ejected gas was expanding faster than the ambient sound speed, so fast that shock waves could not pile up disc gas up in front of the ball. Instead it simply elbowed its way through. The fireball did not expand evenly in all directions because of its clumpy composition. Today's X-ray surface still reflects the under- and overdensities in the original round fireball shape, which we see at the mottled surface structure. After a period of 100 to 200 days the shock wave slows to 200–400 km/sec. At this velocity disc gas can pile up in front of it as compression fronts. After the expanding gas has piled roughly ten times the mass of ambient gas it begins to emit strongly in the optical bands. We see the vivid results of this stage in the blue O III emission in Martin's Vela's shreds. The fronts and their O III / H $\alpha$  gas can be 5 to 20 light years thick.

Slower gas expelled by the star after the initial shock cooled as it expanded. Eventually it caught up with the now-slow shock fronts and crashed into it. The result was a rebound wave which (a) compressed the shocked gas in front of it to incandescence (red H $\alpha$  in Martin's image) and (b) rebounded back toward the original star. It is in the interface of this violent rebound that most cosmic rays are generated. While the earlier X-ray front kept on going, the gas cooled enough to emit in the optical bands—mostly H $\alpha$  and O III—distorted and shredded into the shapes imaged by Martin Heigan. The fact that this ROSAT image was snapped roughly 11,000 years after the initial explosion says a great deal about the violence of a supernova and the feebleness of interstellar gas. Today the X-ray shell is immense—230 light years across—yet it is still hot enough to generate copious quantities of X-rays.

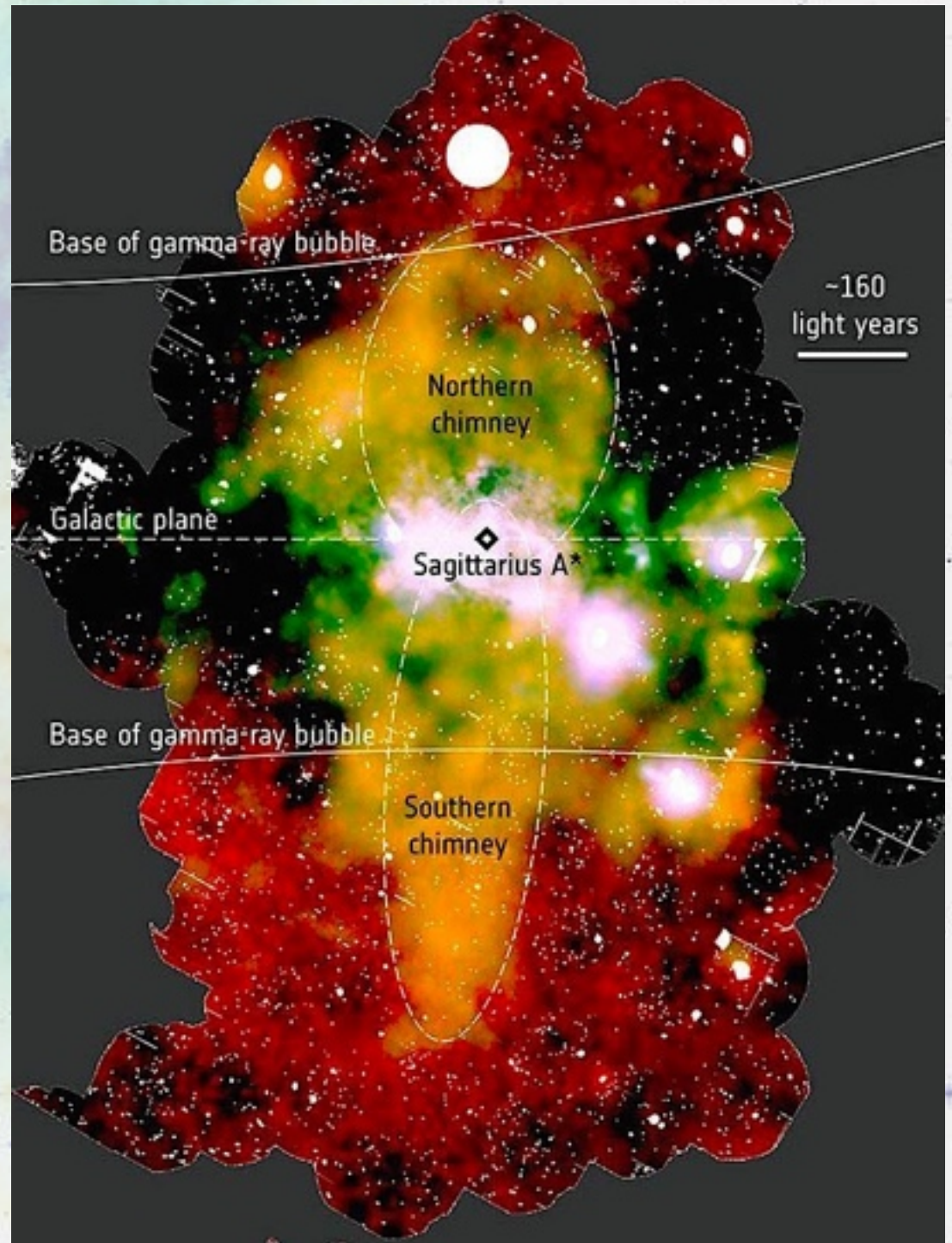


The neutron star at the heart of Vela spins around its axis once every 11.2 seconds (89 milliseconds). Gas spinning around its equatorial plane is funneled toward the poles via magnetic fields. There it is ejected at near-relativistic velocities. The result is a pulsar wind jetting outward along the polar axis. The pulsar wind originated very early in the neutron star's career. The primordial jet blasted through the star's envelope sooner and faster than the cooler optical-band gas behind. One result was that large clumps of the star's matter were ejected whole and intact. Those blobs are still detectable even today. [Watch this ICRAR video to see how it works.](#)

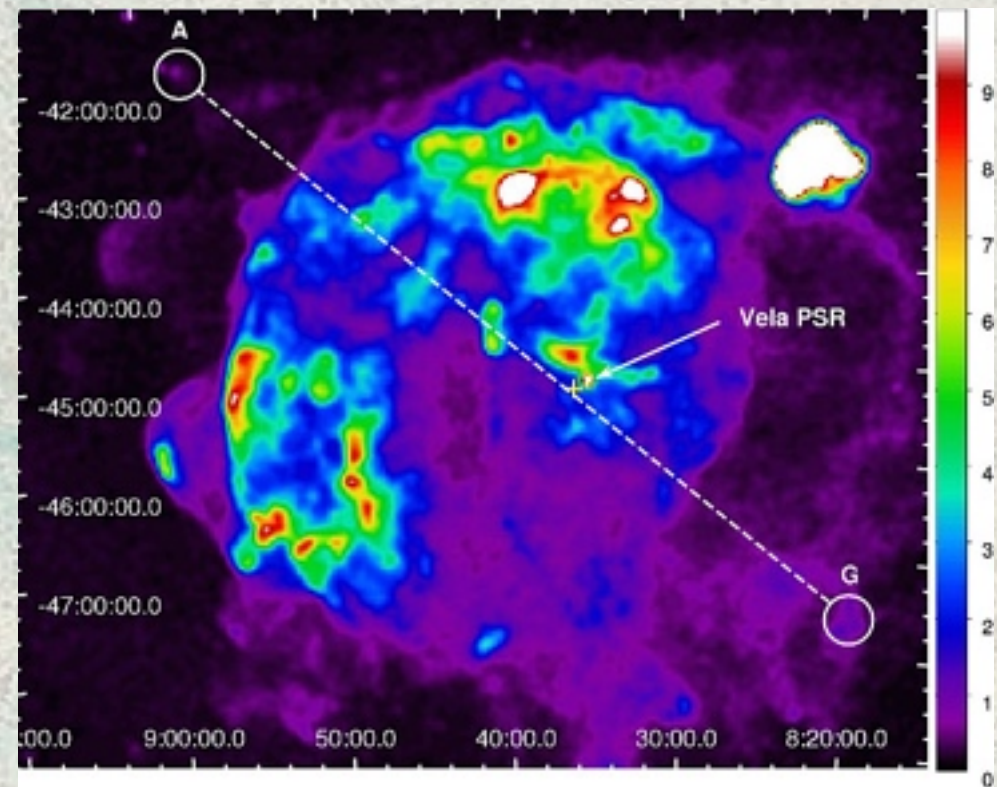
**Right:** Most disc galaxies produce many supernovae going off across a long time span. See the [SILCC simulations](#) to understand what a violent life this makes. Multiple supernovae across a long time, say 100 million years, eventually produce a galactic chimney. Here, the galactic chimney erupting from the centre of the Milky Way (yellow-orange areas) are attributed to the supermassive black hole at the centre of our galaxy, but the same chimney structures result from multiple supernovae. Credit: Gabriele Ponti/MPE/INAF and Mark Morris/UCLA. Read more in this [phys.org](#) report.



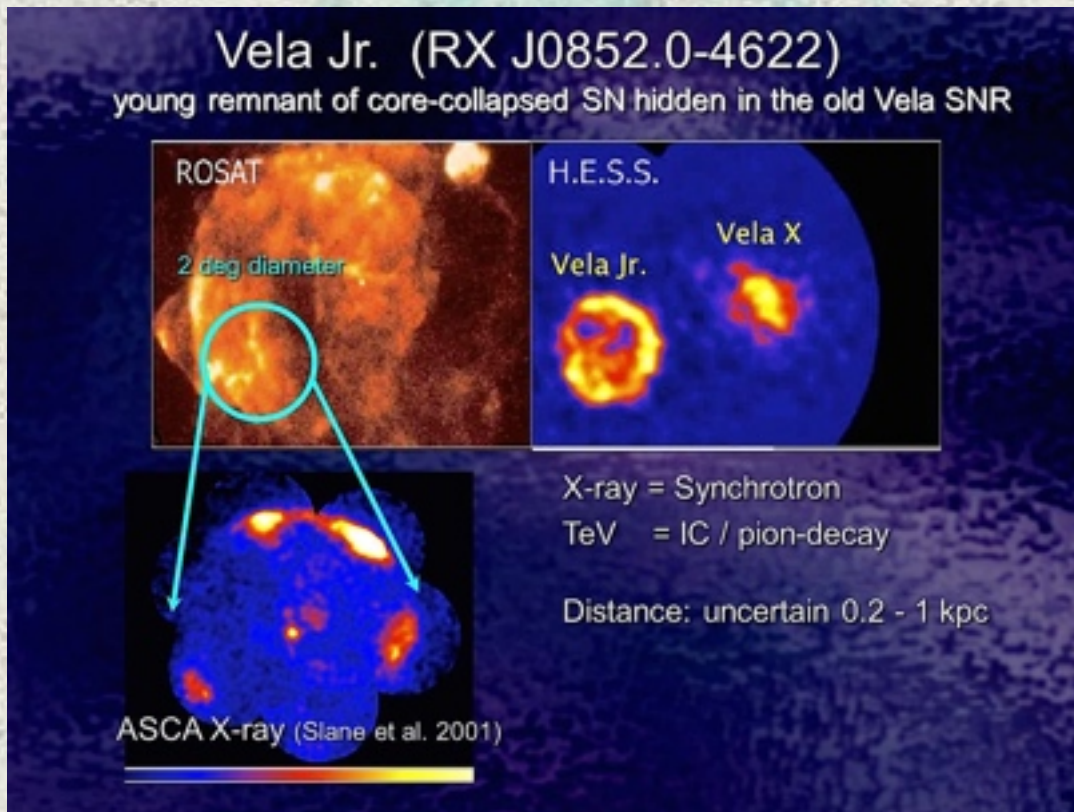
Spectral analysis of the several large blobs A–DD' moving far ahead of the supernova blast wave showed that each of them contained ejecta with different spectral abundances. Fragment A above was silicon-dominated, while fragments B and D were neon, magnesium, and oxygen dominated. These elements are produced in different layers of a star's atmosphere, some so deep (silicon) that they are just above the exploding core. This confirmed the hypothesis that the thick envelopes in a star whose core is undergoing neutron-star collapse are not atomised by the neutrino barrage and mechanical shocks bursting outward from the detonation. Instead, some envelope material is blown off in large clumps. Different clumps originate in different layers of the pre-SN star in which metals of that species dominate.



*Right:* This study of the Vela supernova remnant focused on “shrapnel” matter fragments made of packets of materials ejected from deep within the supernova. The composition of these shrapnel was curious because one of them, indicated by letter A in the image above, shows a high silicon abundance in the X-ray spectrum while other pieces of shrapnel showed a rich content of oxygen, neon and magnesium. Even more intriguing, another bit of silicon shrapnel was detected at the letter G in the image. The Vela pulsar was right in the middle. This suggested that two bits of silicon shrapnel were hurled from the powerful polar jets emanating from the Vela pulsar. The evidence led to the inevitable conclusion that these two bits of shrapnel originally resided in a deep silicon-rich layer of the pre-supernova O supergiant. The silicon layer is where silicon fuses to become iron, generating 3-billion K temperatures. The silicon-burning phase lasts about 1 day, leaving only an iron core behind. Iron does not produce energy when it fuses, it consumes energy. Hence the enormous heat source in the centre shuts down and the iron core collapses into a neutron star. Extreme-energy polar jets were immediately produced by the jets. These hurled large wads of the deep layers straight through the higher layers—just like shrapnel from a grenade. These flew out and are seen today as fragments A and G, well beyond the boundary of the expanding fireball. This complex series of reactions occurred deep in the star in the matter of a few seconds.



Left: The Vela SNR had a few surprises in store for astronomers tracking down the sky’s mysteries in new instruments. In the 2000s the standard fare of X-ray, UV, optical, millimetre, micron, and radio were expanded by the addition of gamma-ray band telescope systems like the [H.E.S.S. twin Cherenkov radiation detector dishes](#) in Namibia. In 2005 H.E.S.S discovered traces of extreme-energy teravolt cosmic rays emanating from the Vela SNR, but off-centre from the Vela pulsar region. Cherenkov radiation is photon emission generated by electrons helixing around magnetic field lines. The H.E.S.S. detections had energy levels 1000 times greater than gamma, produced when extreme-energy cosmic rays strike atoms in the Earth’s atmosphere and initiate a drop-down energy-loss sequence starting with pion decay. Pion decay happens when extreme-teravolt cosmic rays impact ordinary protons. Gamma-energy cosmic rays were already known to originate in the colliding-wind shock front of expanding SNRs, but the H.E.S.S. data suggested that a new source was not actually related to the Vela SNR. Could there be another SNR hiding behind the hot emission of Vela? Six years later a team led by [Yasunobu Uchiyama of the Japanese Susaku satellite](#) team verified suspicions raised in the H.E.S.S. images. Indeed there was a very young “Vela Jr.” pulsar and shell hiding under the skirts of the old Vela.



## The four types of supernova shells

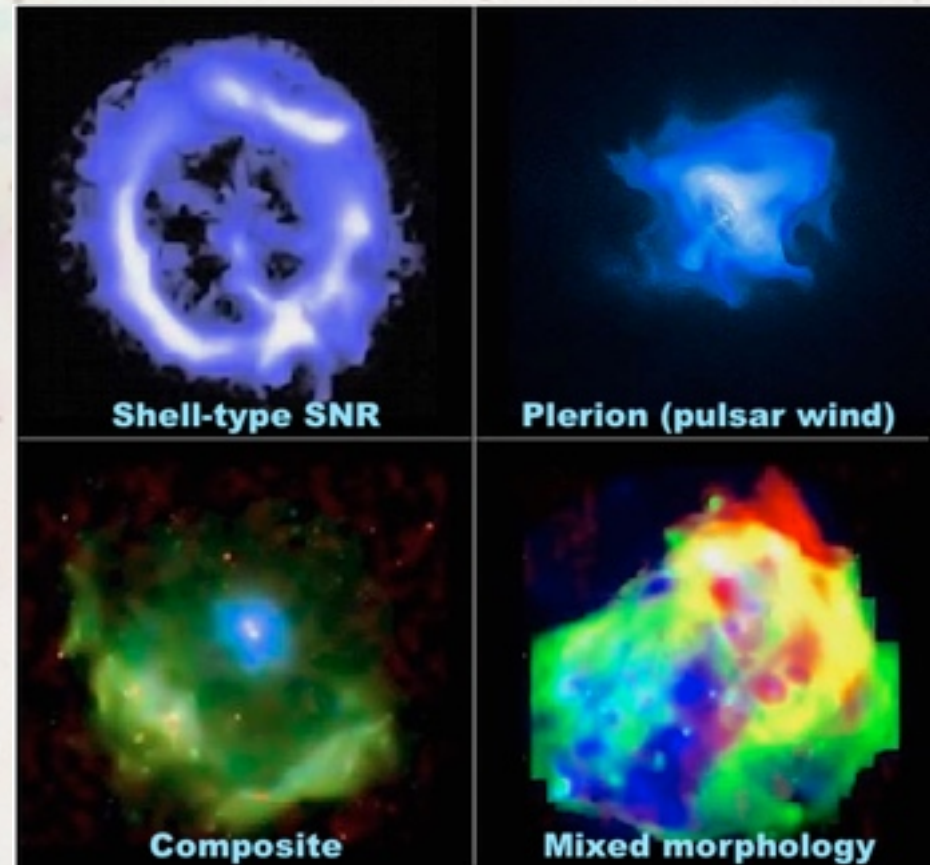
Supernova remnants are roughly classified into four categories based on their morphologies:

**Shell type SNRs** are structurally the simplest of all supernova remnants. They are characterised by a limb brightened shell of shock heated plasma generated as the blast wave of an SNR travels through the ISM. Limb brightening looks like a ring around the stellar remnant. It is caused by more material being along the line of sight near the edges of the remnant. SN rings not only look like a planetary nebula, they respond to an OIII filter like a planetary nebula.

**Plerions**, also know as pulsar wind nebulae have the bulk of their emission radiating from near the centre of the remnant, where there is a rapidly spinning neutron star. They are characterised by a highly energetic wind of relativistic electrons and positrons driven by the neutron star's rotation. [See this ICRAR simulation](#). The wind terminates in a shock where it meets the ISM. There the particles are accelerated to relativistic energies. By diffusing away from the shock, the particles create a nebula of electrons/positrons which emits via synchrotron radiation from radio to soft gamma-ray bands.

**Composite SNRs** are remnants which exhibit a combination of the previous two morphologies, having both a well-defined shell, and pulsar wind nebulae emission. These are mostly young (~20, 000 yr), energetic SNRs containing a pulsar wind nebula that has yet to blow away its shell. Both the shell and the inner pulsar wind nebula are well defined in the radio an Xray bands.

**Mixed morphology SNRs**, also know as thermal-composite SNRs are remnants which display a shell in the radio band, but which exhibit thermal radiation from hot plasma rather than being powered by a pulsar near the centre of the remnant in the X-ray band.



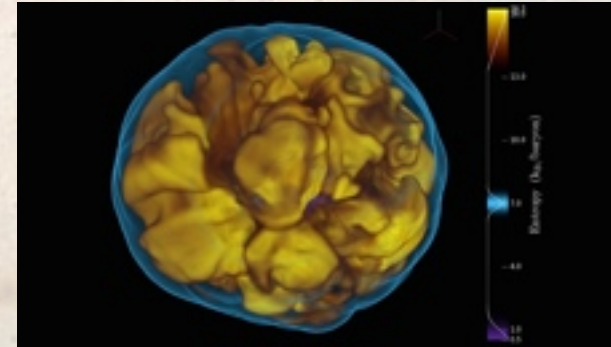
Examples of SNR morphological types. From top left to bottom right:

- (a) (SNR) E0102 - 72, a shell-type supernova remnant in the Small Magellanic Cloud. (Image Credit: NASA/CXC/SAO).
- (b) The Crab Supernova Remnant, the most famous pulsar wind nebula. Notice the centralised emission, shocks fronts, and lack of a shell. (Image Credit: NASA/CXC/Penn State/G.Garmire et al).
- (c) (SNR) Kes 75, notice hard X-ray emission from both a shell, and a pulsar near the centre of the remnant. (Image Credit: NASA/CXC/GSFC/F. P. Gavriil et al).
- (d) Thermal composite (SNR) 3C 391. This image is a composite of X-ray emission (blue), radio emission (red), and IR emission (green).

Over its lifetime, the dynamics dictating a supernova remnant's expansion, temperature, and radiation change dramatically. Depending on the specific mechanism dominating the remnant's evolution, the explosion surface passes through three successive phases. The transition from one phase to the next occurs over hundreds, even thousands of years, hence there is no well-defined cutoff point between one phase and the next.

- **Free expansion phase:** During this phase, ejecta from the explosion sweeps through the ISM, creating a shockwave of superheated plasma. This phase is characterised by nearly constant temperature and expansion velocity of the shock boundary. The phase comes to an end once the shockwave has swept up enough mass from the ISM to equal to about ten times the mass of ejecta itself. This phase can last up to the first two hundred years after the explosion. Its duration depends on the density of the ISM surrounding the progenitor star.
- **Sedov/Adiabatic phase:** The material swept up by the shockwave slows down its expansion. Deceleration is related to how much cool gas is swept up into the ejecta. [Rayleigh-Taylor instabilities](#) develop in the shock boundary, which causes the shocked ISM to mix with the ejecta. The mixing of material fills in the magnetic hole inside the SNR shell. This phase usually lasts from 10, 000 to 20, 000 years. The Vela SNR is early in this phase right now
- **Radiative phase:** This phase is characterised by slower cooling of the remnant's shell. Once the remnant has cooled to  $\sim 10^6$  K, recombination of electrons and heavier atoms occurs. Recombination cools the remnant, in a runaway loop that increases the rate of subsequent recombinations. The remnant begins to cool exponentially. Eventually it has cooled so much that the bulk of its emission radiates in the optical. This explains why almost every image of a Type 1a or 2b detonation supernova shows the shock ring as a large circle quite far from the central star. It has taken thousands of years to get there, but was not visible in the optical bands to our eyes and telescopes until its gases cooled to levels that emit visual-band radiation. The most notable visual-band radiation is OIII, the 500.7 nm wavelength in the blue-green spectrum that amateur astronomer look for when using OIII filters.

All the while, the expansion velocity of the shockwave decreases, the shockwaves becomes less and less defined as time goes one. This phase can last for millions of years, as the remnant mixes with the ISM and eventually becomes unrecognisable.



[Watch a supernova detonate here.](#)

[Supernovae were originally classified](#) on the basis of their optical properties. Over time observations and modeling have refined their classification to more accurately trace to the specific types of stars of 8 solar masses or more that eventually explode as supernovas.

- **Type II, Type Ib, and Type Ic** explosions are produced by the catastrophic collapse of the core of a massive star.
- **Type Ia** supernovae are produced by a sudden thermonuclear explosion that disintegrates a white dwarf star.
- **Type Ib and Type Ic** supernovae show many of the characteristics of Type II supernovae, but they differ from Type II in that they lose their outer hydrogen envelopes prior to the explosion, either through the ejection of copious amounts of their hot interior envelope matter from unstable convection currents, or because the outer envelope was pulled away by a massive companion star.
- **Type II** supernovae occur in regions abundant with bright, young stars, such as the spiral arms of galaxies. They have not been observed in in elliptical galaxies because "red and dead" elliptical galaxies are dominated by old, low-mass stars.

# The technical stuff

Supernova ejecta drive a blast wave through any CSM from the progenitor system. As material is swept up, a reverse shock forms in the ejecta, reheating them. The ejecta-driven phase lasts until ten or more times the ejected mass is swept up into the expanding blast shell, and the remnant approaches the Sedov or self-similar evolutionary phase. The evolution up to this time is approximately adiabatic. **Adiabatic** means that no heat enters or leaves the system. In the case of an supernova remnant very much hotter than its surroundings, the only means by which the superheated gas can come to thermal equilibrium with the surrounding Galactic disc gas is by expanding. The hotter the adiabatic gas parcel, the faster it expands.

The blast wave slows over time periods of 10,000 to over 1 million years. All the while the shock wave's velocity through space is slowing due to its overall expansion. We saw the various optical appearances of these slowing shock waves in the second and third images above.

During the **Sedov or mass-accumulation phase** the remnant age approaches the cooling time for immediate post-shock gas, and the shock becomes radiative and highly compressive. This is the phase we are most familiar with because it is when we can see the ubiquitous glowing rings around a white dot of a star in the middle. Note that *we cannot see a supernova remnant before this* while it is smaller and hotter, because it emits light in the UV and X-ray bands invisible to us optically. Eventually the shock speed drops below the local ISM sound speed (20 km/sec as a convenient rule of thumb) and the remnant dissipates. This can take millions of years, as we saw in the images above.

The SN blastwave or forward shock begins to decelerate almost immediately as it moves into the surrounding interstellar gas, heating it to X-ray emitting temperatures. There is a “contact discontinuity” from 1 to 4 light-years thick across which the pressure is roughly constant. This zone of very hot gas is where cosmic rays get their start and acquire their enormous energies.

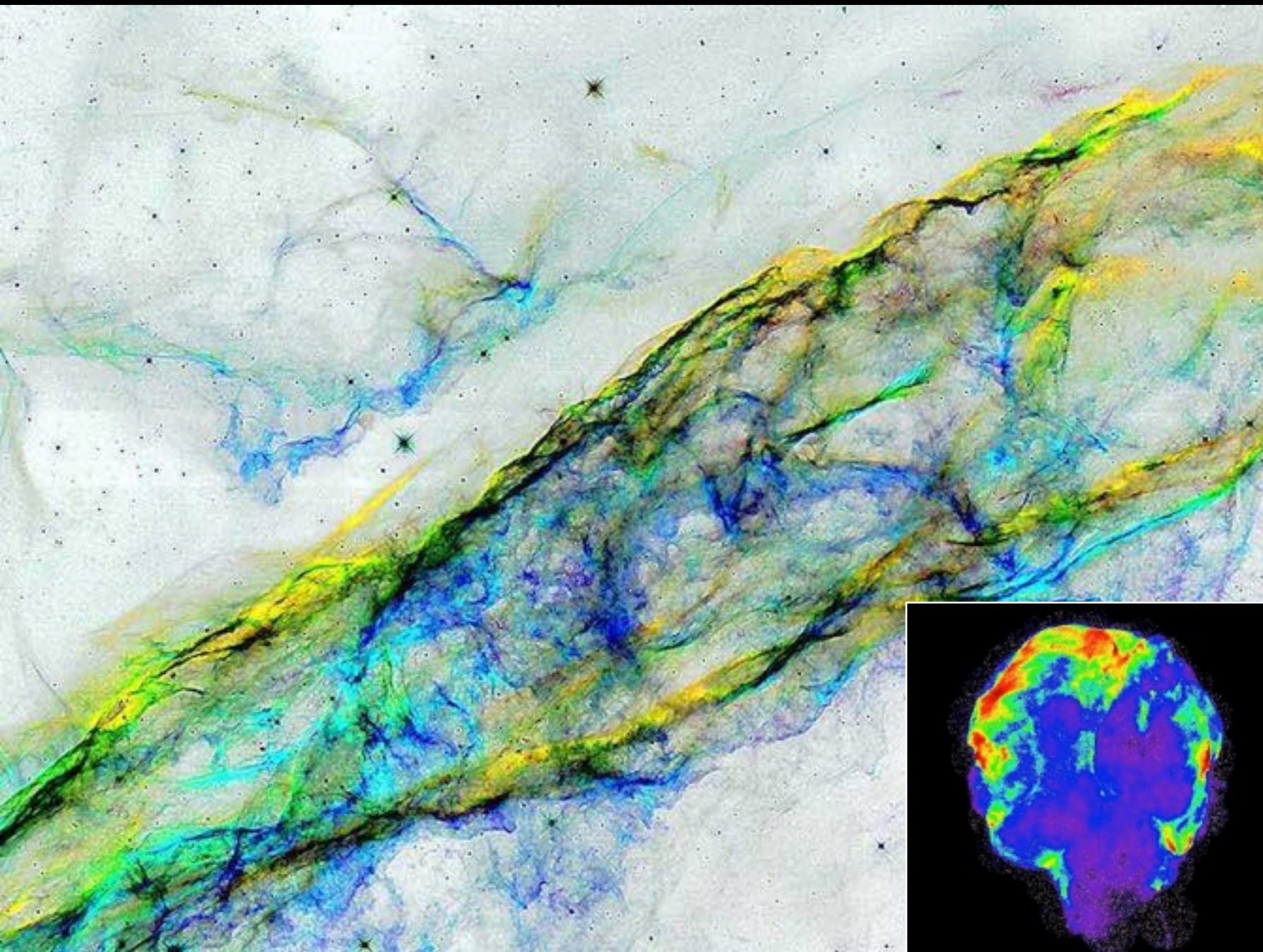
**Reverse shock:** The rapid expansion of the early stages cools the ejecta adiabatically to very low temperatures, so that even a small amount of deceleration of the blast wave results in a velocity difference that is greater than the sound speed in the cold ejecta. This forms an form of acoustic wall (commonly referred to as “reverse shock”) which reflects incoming radiation from the star back toward the star. This in turn reheats the ejecta. Reverse shocks are known in even very young supernova blast waves. The evolutionary stage in which both forward and reverse shocks are present can last for hundreds to thousands of years. It is sometimes called the “ejecta-driven” stage.



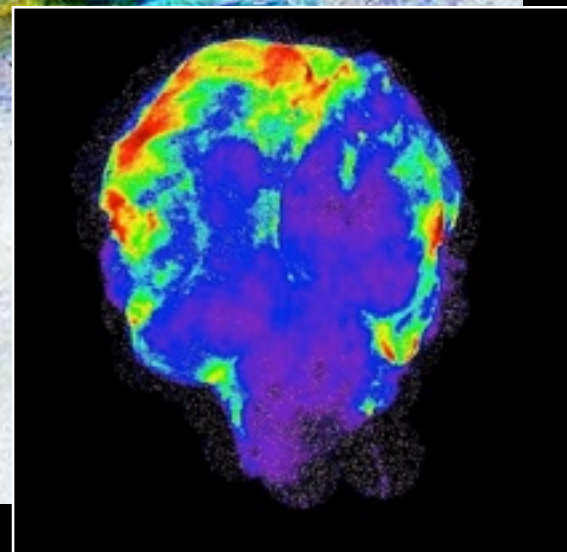
**Rayleigh-Taylor instability** produced the thin fingers and streamers in the Crab Nebula supernova remnant. These occur when thin, hot gas pushes into a thin, denser cold gas. R-T effects are ubiquitous and drive the unusual morphologies of supernova remnants.

As the blast wave decelerates, the time scale for radiative cooling of the shocked material becomes comparable to the remnant age. Cooling is typically by UV, optical, and near-IR fine structure transitions of C, O, and Fe. This is normally for shock speeds  $v_s \sim 200 \text{ km s}^{-1}$ , which corresponds to a remnant age of 10,000 years. The Vela SNR is between 11,000 and 12,000 years old.

By this time most remnants have been interacting with inhomogeneous ISM for some time and are quite irregular, as we see in Martin's image. Densities in the blue cooling shock waves so evident in Martin's image can be quite high,  $>10,000 \text{ K}$ . Since the ambient gas in the neighbourhood is cold and very thin, these blue arcs and streamers will expand indefinitely without losing much energy. The longevity is affected mainly by magnetic field pressure in the Galactic spiral arm magnetic field. Radiative-phase remnants can be quite bright in the optical band, as Martin's image attests. Eventually, shock speeds become comparable to local sound speeds (avg.  $20 \text{ km sec}^{-1}$ ) and the SNR dissipates into the ISM. Don't quit your day job hoping to see it tonight.

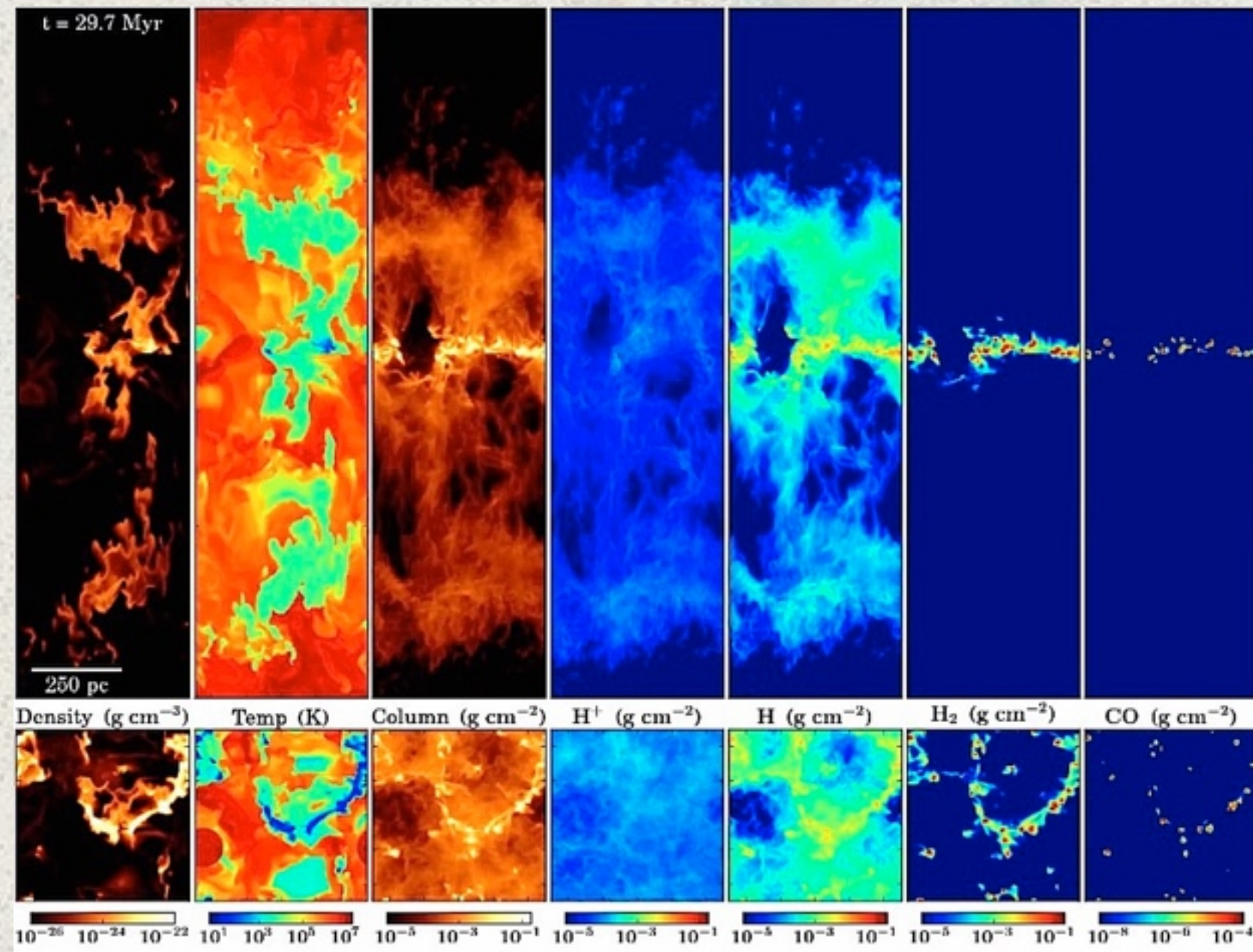


Section of the Eastern Veil in the Cygnus Loop supernova remnant. Image colour-inverted to emphasise temperature gradients and helixing by magnetic fields. Yellow = cool @  $\sim 6.1$  million K, blue = warm @  $\sim 6.3$  million K, black = dust extinction. As expected from a supernova remnant, the inside face is warmer than the central region, which is in turn warmer than the expanding outer surface. The Cygnus Loop is approx. 20,000 years old and expanding at 290 km/sec.



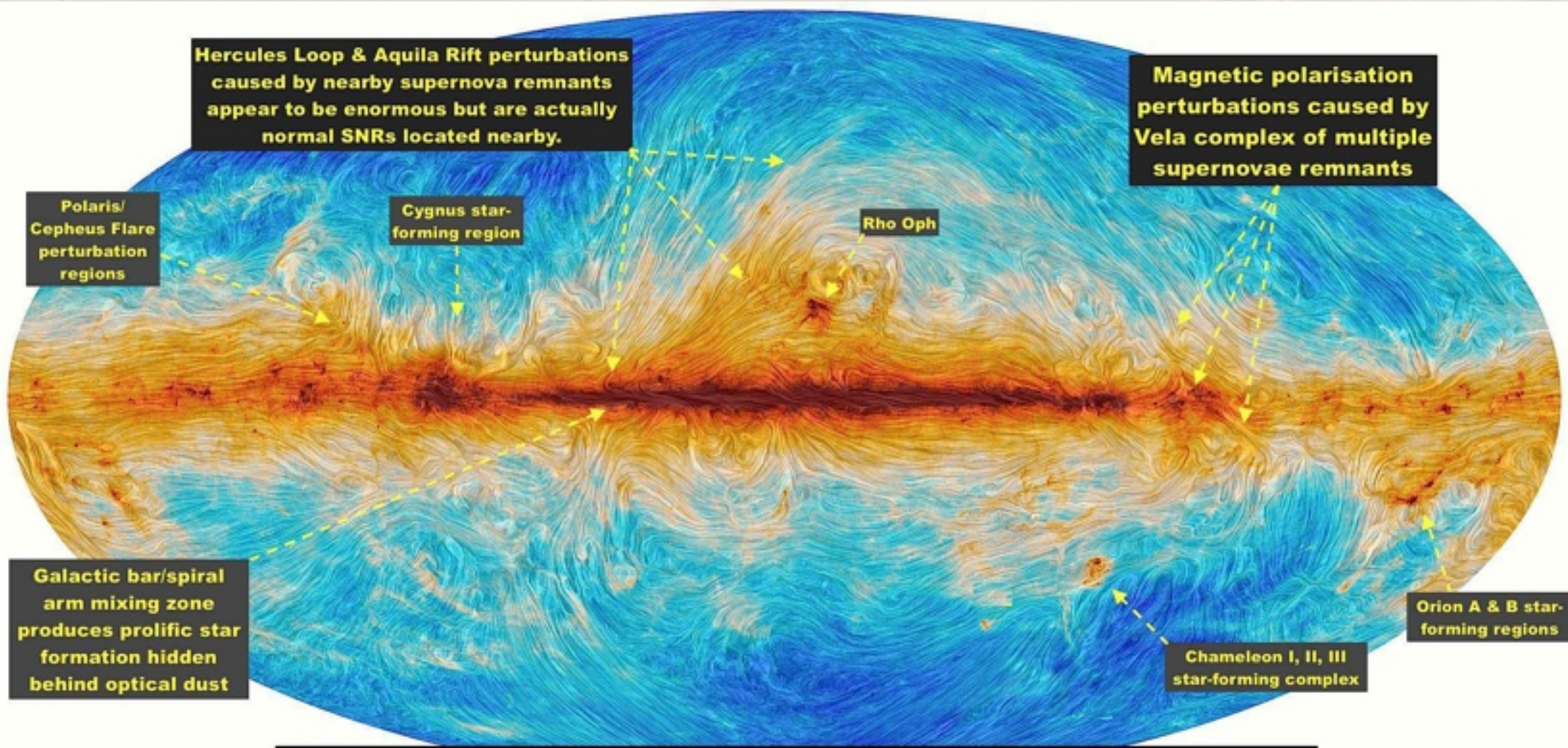
## SILCC sim S10-KS-clus, 15 SN/Myr, clustered driving, 20% of SNe detonations are Type Ia white dwarf.

An individual supernova makes many changes in the way its neighbourhood evolves over the first 10,000 to 20,000 years of the explosion. The metallicity of interstellar gas is enhanced by the metals hurled into space by the blast. The disc's magnetic field has a hole blown into it by the super-hot gas ejecta, which takes centuries to restore. New, small star clusters sometimes form on the rim of an expanding shell if it passes through a molecular cloud already dense and cold enough to undergo free-fall collapse. Particularly powerful blasts eject gas out of the thin disc into the thick disc and halo. The overall gas distribution in a galaxy is profoundly influenced by supernovae, especially in the very long term. When one steps back and looks at the life of a galaxy disc over 10 million years, anywhere between 50 and 100 supernovae may go off. The disruptive effects are visually spectacular while they also alter the composition and evolution of the disc. [The SILCC Project in Garching, Germany](#) has a fascinating array of simulations that show what happens to specific properties, e.g., gas temperature, metallicity, and gas available for future star formation, over cycles of a million years.



This is a snapshot of the state of a galaxy disc 29.7 million years after the beginning of a simulation calculated using 15 supernovae per million years. By this point 447 supernovae have exploded. The upper band shows gas distribution and temperature from the side; the lower squares show it as if seen from above. [Running the full sim](#) is a breathtaking lesson that our galaxy disc is a very violent place, about which we are blissfully unaware because of the enormous time scales involved.





Hercules Loop & Aquila Rift perturbations caused by nearby supernova remnants appear to be enormous but are actually normal SNRs located nearby.

Magnetic polarisation perturbations caused by Vela complex of multiple supernovae remnants

Polaris/Cepheus Flare perturbation regions

Cygnus star-forming region

Rho Oph

Galactic bar/spiral arm mixing zone produces prolific star formation hidden behind optical dust

Chameleon I, II, III star-forming complex

Orion A & B star-forming regions

**Planck 353 GHz magnetic fields lines revealed in polarised dust particles**

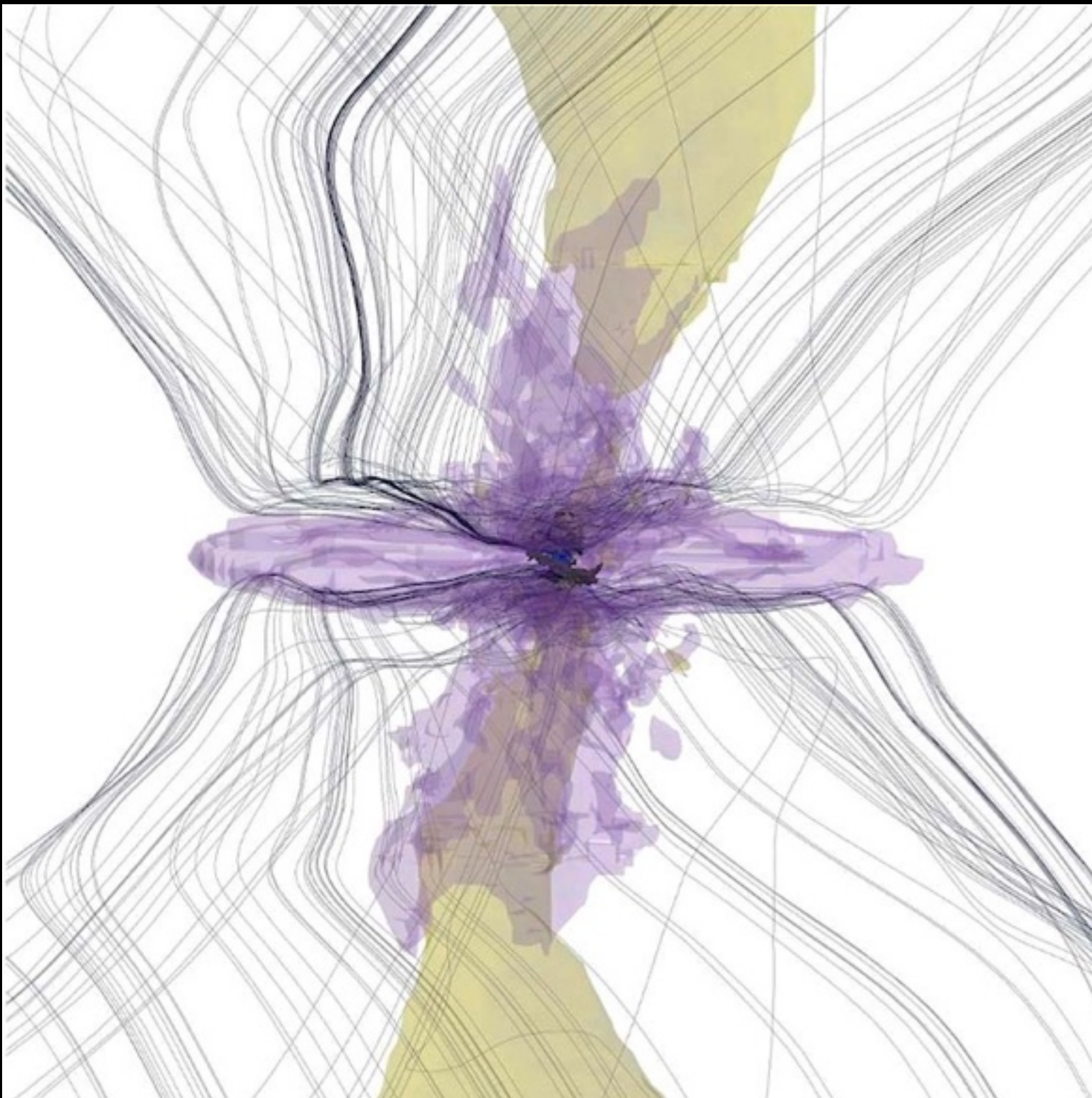


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**Events in space take place on such a physically large and long time scale that we do not notice what a violent place it is.**



Magnetic field lines in a strongly magnetised neutron star. The severely bent lines from the top and bottom edges to the centre are Birkeland currents flowing along magnetic field lines descending toward the star. The currents are veered inward by the intense gravitational and magnetic fields of the star, then reverse and flow outward along paths similar to when they entered. Birkeland currents also cause the auroras around the Earth's magnetic poles. The star is circled by a dense accretion disc of matter caught up and trapped by the magnetic field of the star. When the particles near the star they are caught into the Birkeland currents and ejected out the poles of the star. Electrons follow the currents; ions eject at relativistic velocities out the polar axes. [Watch this simulation from ICRAR in Australia. Diagram source paper here.](#)

# Barbara Cunow's Caldwell Project

This is a collage of the Caldwell objects which I obtained with my DSLR on a tripod without tracking. Because the Caldwell objects cover almost the complete declination range from  $-90^\circ$  to  $+90^\circ$ , I had to use two observing sites to complete the catalogue. I took the images of the southern objects from my urban home in Pretoria with the exception of the Coal Sack image which I obtained at a dark site in Namibia. The images of the northern objects were taken at my parents' place in northern Germany.

The focal lengths I used varied between 50 mm and 200 mm (with the exception of the Coal Sack and Hyades images which were taken with a focal length of 18 mm), so most of the objects appear quite small on the images, and I used the original sizes when I put together the collage.

The methods for obtaining the images and for processing the data are the ones I already used for the collages of the ASSA Top-100 and the Bennett objects. Because of the sky rotation each image has to be taken with a very short exposure time, typically a few seconds. So in order to get a good signal I take hundreds of short exposures of the same star field and then stack the images. By doing that the noise is reduced dramatically and the objects become visible.

When I worked through the Caldwell catalogue, I discovered that this catalogue is more difficult to complete than the ASSA Top-100 and the Bennett catalogues, and also more difficult than the Messier catalogue. The reason is that the Caldwell catalogue contains a few bright nebulae with a very low surface brightness which are extremely difficult to photograph. These include the Iris Nebula (C4), the Cave Nebula (C9), the Crescent Nebula (C27) and the western segment of the Veil Nebula (C34). All these objects are only hardly visible on my images, but something can definitely be seen of each of them.

- Barbara Cunow

## *Ed. note:*


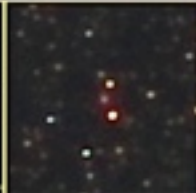



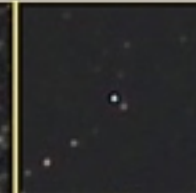
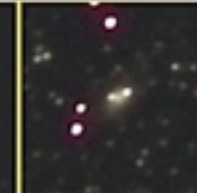





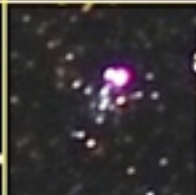

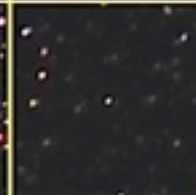



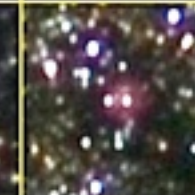


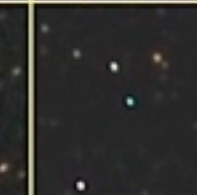



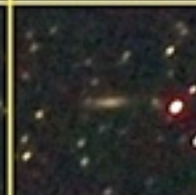
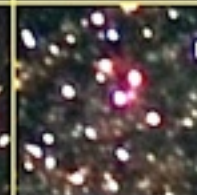


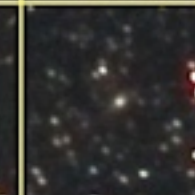





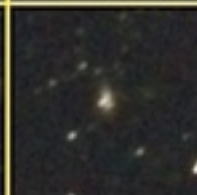



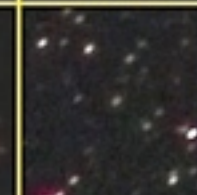

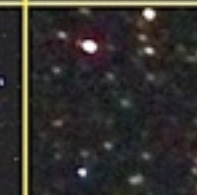




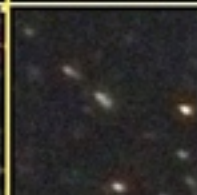
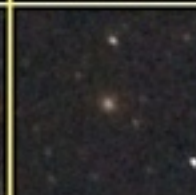






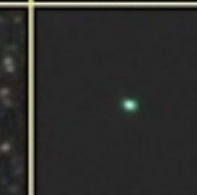
The Caldwell Catalogue was compiled in 1995 by Sir Patrick Moore. He has said he started it for fun because he had some spare time after finishing writing up his latest observations of Mars. He looked at some nebulae and found many that Charles Messier had not listed in his catalogue. Messier was only interested in listing those objects which he thought could be confused for the comets, Messier also only listed objects viewable from where he observed from in the Northern hemisphere. In Sir Patrick Moore's own words,

*The idea of the Caldwell Catalogue came to me one night, after I had been observing the Moon (my own subject) and had looked casually at the Perseus Sword-Handle. This has no Messier number. (Messier catalogued nebulae as 'objects to avoid' during his comet searches, and in any case limited himself to the northern part of the sky.) There are many Messier clubs. Why not draw up a catalogue of bright nebular objects omitted by Messier?*

*I did so - and more or less on the spur of the moment, sent it off to Sky and Telescope. To my surprise it caught on, and by now everyone seems to use the Caldwell numbers. I could not use M numbers, because Messier and Moore begin with M — but my proper name is hyphenated (Caldwell-Moore), so I used C.*

*I wish you luck, and clear skies!*

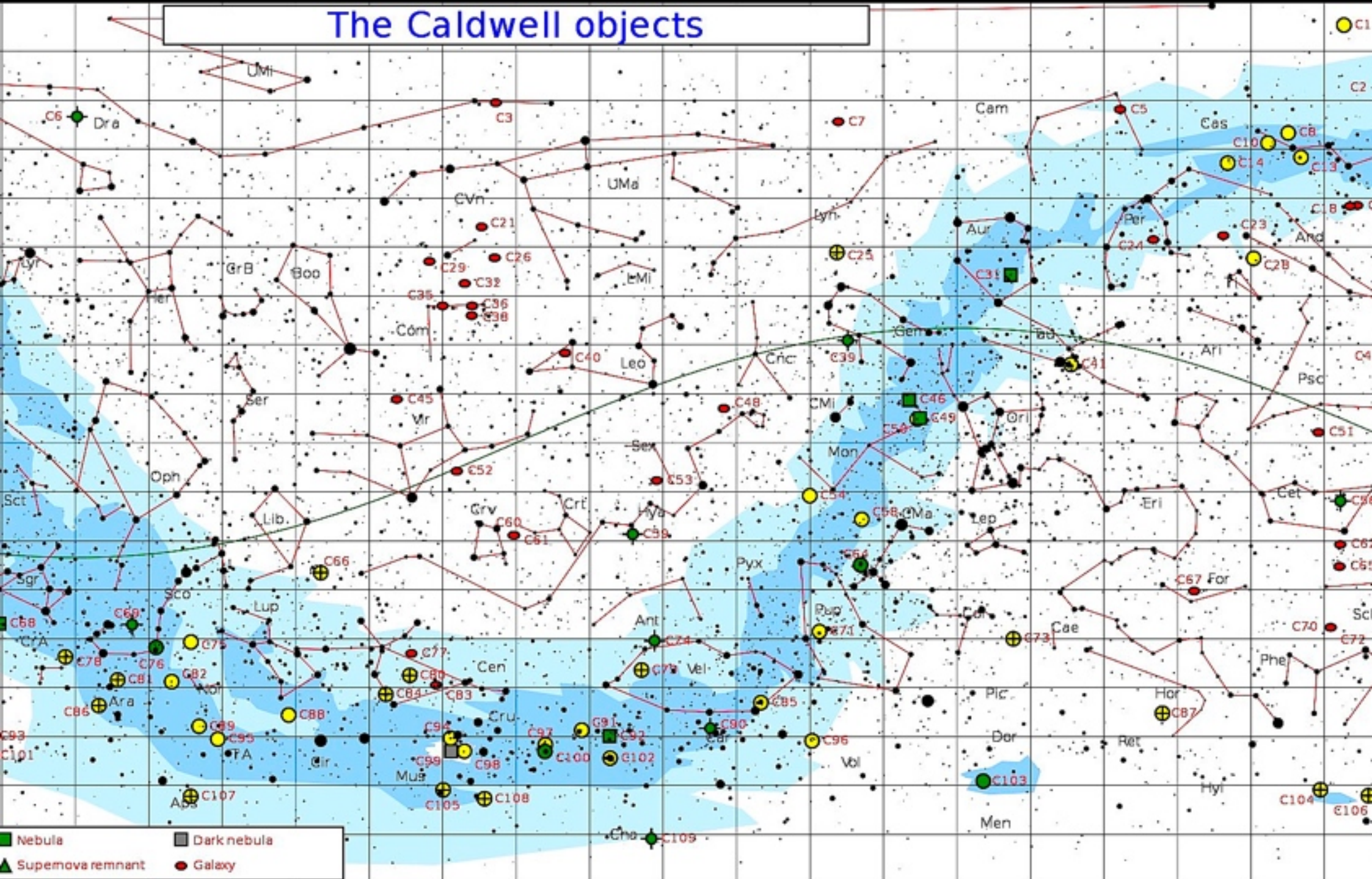
# The 109 Caldwell Objects

										
C1 NGC 188	C2 NGC 40	C3 NGC 4236	C4 NGC 7023	C5 IC 342	C6 NGC 6543	C7 NGC 2403	C8 NGC 559	C9 Sh2-155	C10 NGC 663	C11 NGC 7635
										
C12 NGC 6946	C13 NGC 457	C14 NGC 869/884	C15 NGC 6826	C16 NGC 7243	C17 NGC 147	C18 NGC 185	C19 IC 5146	C20 NGC 7000	C21 NGC 4449	C22 NGC 7662
										
C23 NGC 891	C24 NGC 1275	C25 NGC 2419	C26 NGC 4244	C27 NGC 6888	C28 NGC 752	C29 NGC 5005	C30 NGC 7331	C31 IC 405	C32 NGC 4631	C33 NGC 6992/5
										
C34 NGC 6960	C35 NGC 4889	C36 NGC 4559	C37 NGC 6885	C38 NGC 4565	C39 NGC 2392	C40 NGC 3626	C41 Hyades	C42 NGC 7006	C43 NGC 7814	C44 NGC 7479
										
C45 NGC 5248	C46 NGC 2261	C47 NGC 6934	C48 NGC 2775	C49 NGC 2237	C50 NGC 2244	C51 IC 1613	C52 NGC 4697	C53 NGC 3115	C54 NGC 2506	C55 NGC 7009



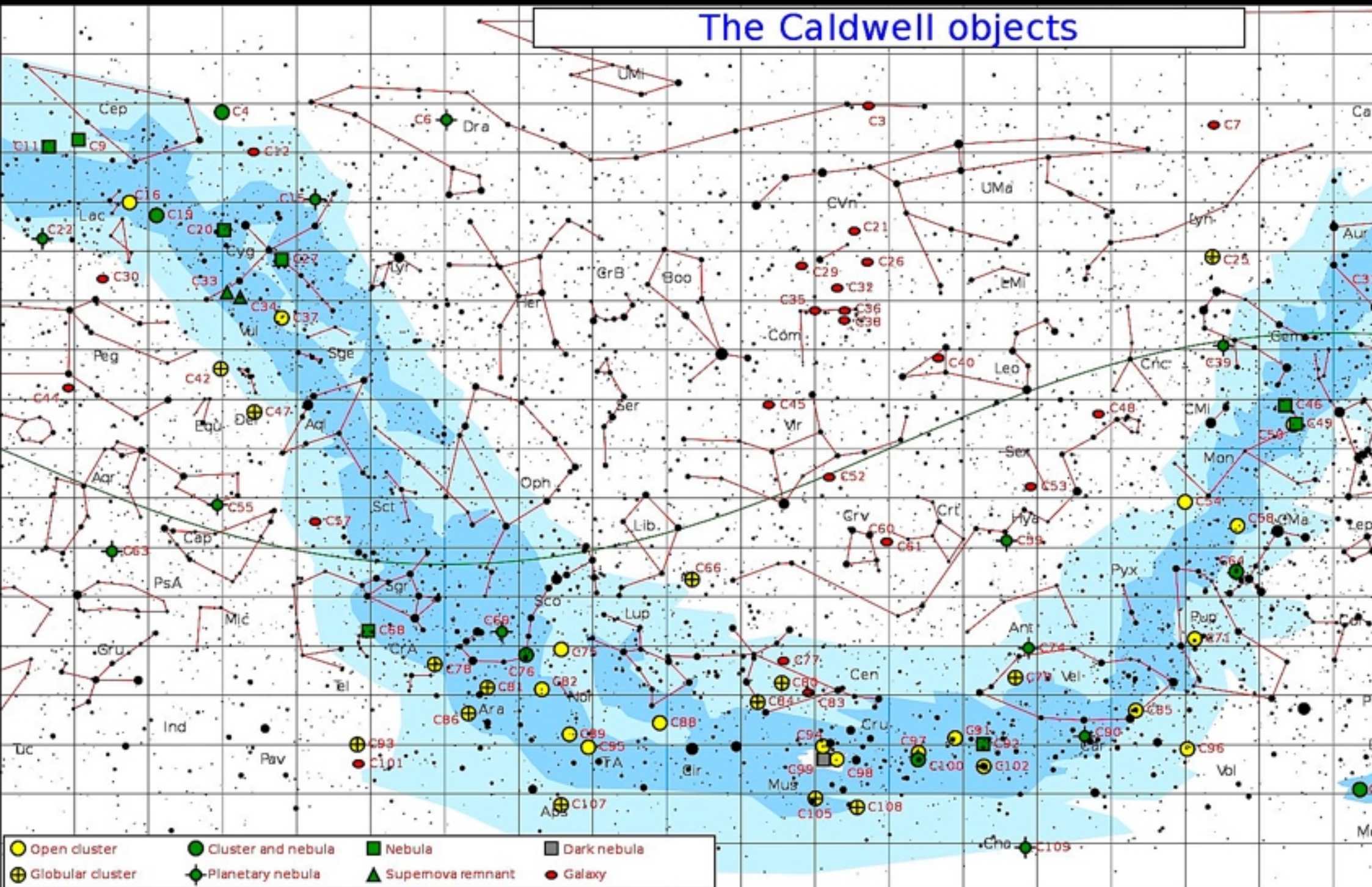
Images taken by Barbara Cunow, Pretoria

# The Caldwell objects



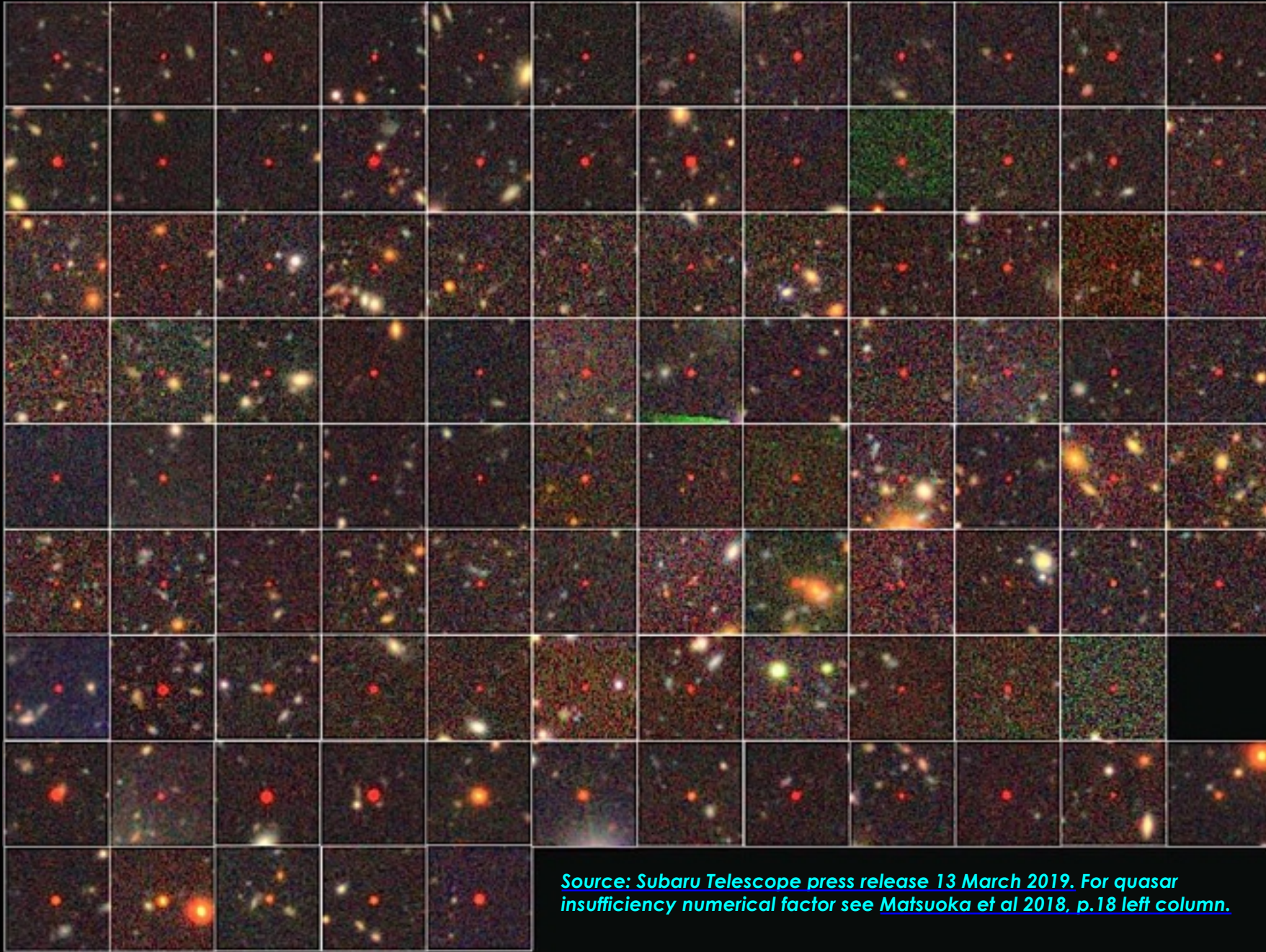
[Visit this website](#) for a downloadable list of links taking you to every object on the Caldwell list.

# The Caldwell objects





# Ed note: Image grid used to present the discovery of 83 new quasars



Barbara Cunow has been using the image grid to very good effect in her DSLR image series. She has done the ASSA Top 100, the Jack Bennett Catalog, and now Patrick Moore's back-of-the-envelope Caldwell catalogue. Barbara's method packs a lot of information into a compact form that makes it easy to spot visual analogues.

This year an international team of astronomers used the Subaru Telescope on Mauna Kea in Hawaii to find 83 previously unknown quasars dating from the first 700 million year of the Universe's existence. These added to the 17 already known. They used the image grid to present their results in a compact form.

Quasars that energetic are powered by supermassive black holes (SMBH) of hundreds of million to billions of solar masses. Just how SMBHs that huge were assembled when the universe was still a toddler is a mystery. That was the era when the first globular clusters were condensing and before galaxies were a dust mote in the universe's eye. The Subaru team used the same technique as Barbara to show their results to the world.

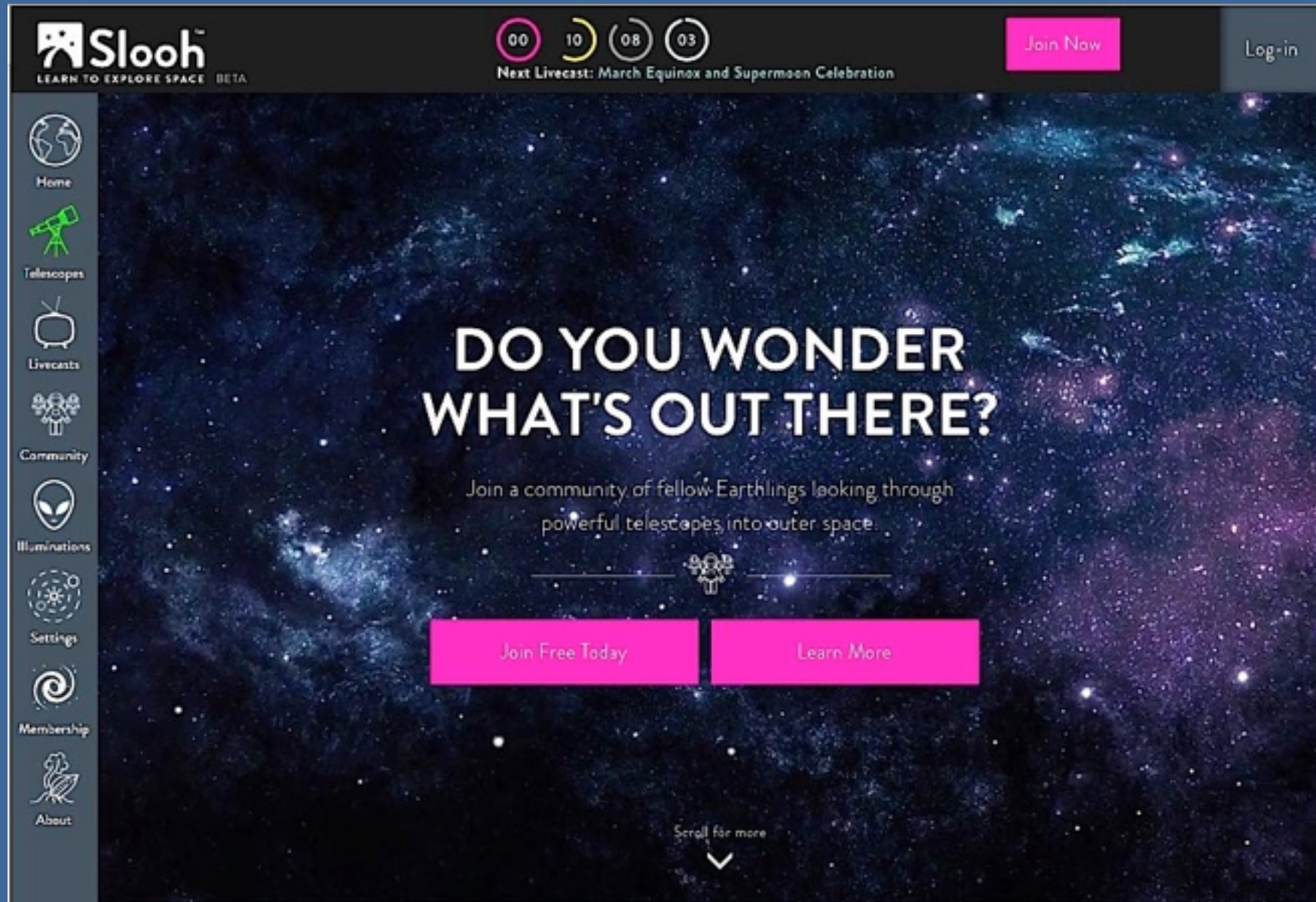
Source: Subaru Telescope press release 13 March 2019. For quasar insufficiency numerical factor see [Matsuoka et al 2018, p.18 left column.](#)



Milky Way over dry creek waterfall near Sutherland. Image by [Tanja Schmitz on Karoo Nights](#).

# My experiences with using SLOOH

Carol Botha



SLOOH knows how to make a case for itself. [Click here for a full-motion "fly through space" gif.](#)

## *The big scopes in the Canary Islands and Chilean Andes are only a SLOOH away*

When I joined Slooh I went with the option: Slooh Crew account, following other members' missions on the telescopes and taking images as the ccd cameras produced them. I soon found my way around and was lured by the idea of being able to control my own missions. The switch to Apprentice membership allowed me five telescope reservations per month as well as access to all the livecasts . To be able to choose my own targets from Slooh's top 500 objects was exciting. I became familiar with taking images, making reservations or piggybacking on other members' missions. In due course I decided to switch to Astronomer membership and to full freedom of being able to reserve objects from the major catalogues or having the telescope point at celestial co-ords of my choice

Before I joined Slooh my main method of deep-sky observing was sketching at the eyepiece which I still enjoy doing as I find more of a connectedness with the object. Although my list of observed objects grew at a steady pace - it was nowhere as extensive as those whose logs were being complimented by astro-photos.

I also became fearful of the day when I would no longer be able to handle the weight of my telescope. A life without astronomy is. Online observing became an attractive alternative, not only for the future but to complement my current work at the eyepiece as well.

### CURRENTLY FEATURED OBJECTS

OK, THERE ARE BILLIONS OF ITEMS OUT THERE TO CHOOSE FROM, BUT WE HAVE TO START SOMEWHERE...

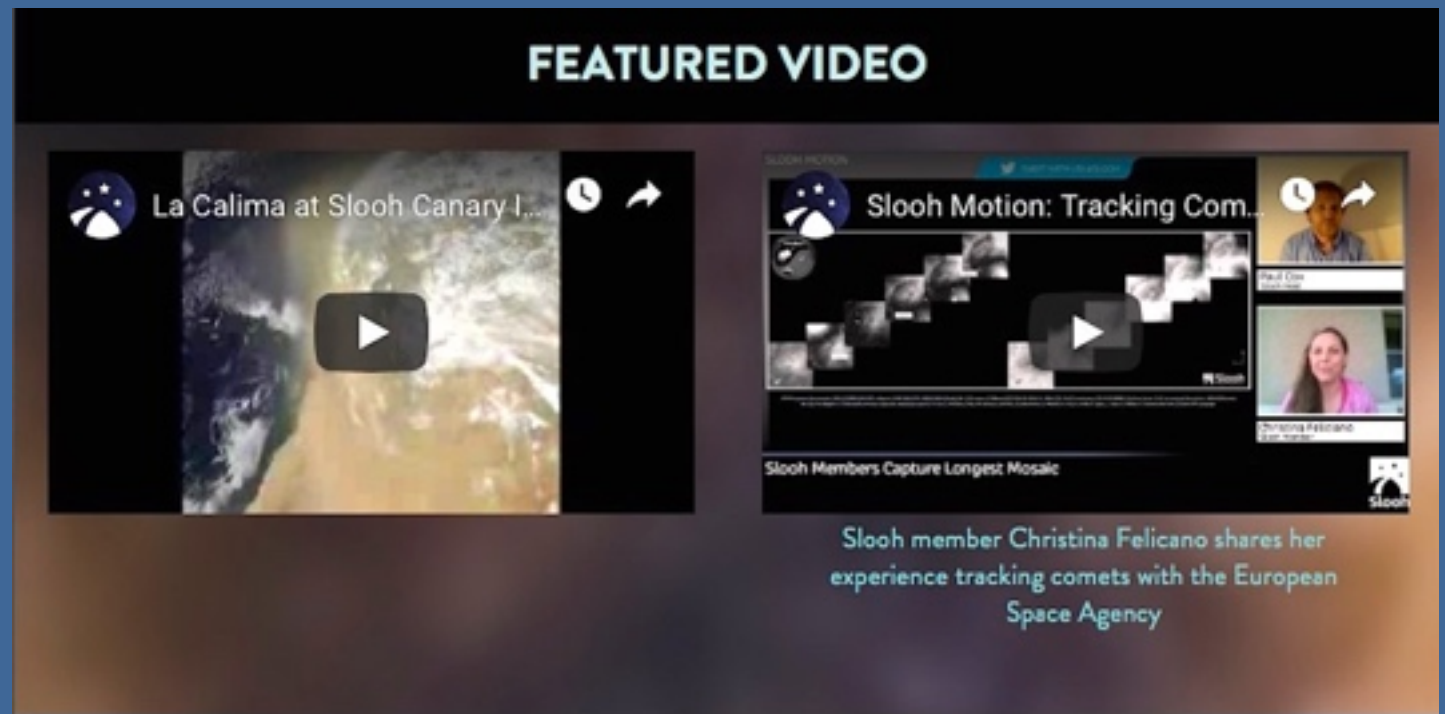
				
THE TARANTULA NEBULA	CASTOR - A GEMINI TWIN	POLLUX - A GEMINI TWIN	WHIRLPOOL GALAXY (M51)	ORION NEBULA (M42)

We've curated a catalog of our members' favorite objects and events in the night sky which we call the Slooh 500. These are the best looking objects to see through our telescopes which also have the most interesting folklore created in their name. Our community forms around them.



I looked at various options and felt most comfortable with Slooh .The layout of the website and accessibility appealed to me as well as the friendliness and acceptance by other members – even from the ones who are doing serious research. We meet up on the discussions pages where everyone is willing to help with issues we might be having , like needing one extra image to complete a task.

To tell readers about all the positive aspects of Slooh would take a few chapters.



- I get to use four telescopes and one solar telescope on the Canary Islands, adjacent to Mt. Teide, Spain and one in Chile, in the hills above La Dehesa.
- Attending online “classes”, like the astronomy course conducted by Dr Paige Godfrey last year, are super fun - not just basic intro- to- astro stuff. Gravitational waves, dark matter, three dimensional thinking and string theory are discussed. So far I have not missed one "class"
- My completed assignments include galaxy classification and stellar classification
- I sat glued to my computer, completing a Messier Marathon hosted by Paul Cox last year and will be repeating that in March 2019. The marathon starts when the sun sets over the Canary Islands and ends at daybreak when Chile One’s dome closes.



- Every night I notice missions by the A-team (These are the guys and gals that track faint comets and asteroids). Those who wish can do a specialised course to become a member of that group. They have an excellent track record.
- Slooh celebrated the Supermoon on 19 Feb 2019. The Supermoon Challenge was exciting. We each had to take images of the Moon over two weeks preceding full moon, then do an animation or montage of the growing gibbous Moon, culminating in the Supermoon. Our efforts were applauded by the hosts during a special livecast.
- On Slooh we may write about arts and culture, astro poetry, science logs, the human spirit - even DIY.
- We have Helen Avery, who brings constellations to life with her incredible knowledge of myths and legends and her beautiful portrayal of these ancient tales.

## ILLUMINATIONS OF THE FULL MOON

**SCIENCE LOG**



**ART & CULTURE**



**HUMAN SPIRIT**



**DIY**



---



**Karen Stevens**  
GUARDIAN ASTRONOMER  
Member since 2016

 **82** Like

### ONCE IN A BLUE MOON

The phrase Blue Moon has two definitions, but both of them refer to an extra Full Moon in a given period – not the Moon’s color. “Blue Moon” originally described the third of four full moons in a quarter (which normally has just three) but now has also come to mean the second of two full moons to occur within a single calendar month. On rare occasions, however, the Moon will actually take on a bluish tinge. Large smoke or dust particles (greater than 0.7



**Brian Ventrudo**  
APPRENTICE  
Member since 2016

 **43** Like

### GRIMALDI CRATER

The Full Moon is a fine spectacle to observe with your unaided eye or a pair of binoculars. But most experienced stargazers know the Full Moon is not an ideal sight to explore with a telescope. That’s because the long shadows that appear at earlier and later phases disappear, which makes the Moon’s craters and mountain ranges appear stark and featureless on a Full Moon. The Full Moon can also be uncomfortably bright to view in a telescope. But there is one fascinating

### Constellation Illuminations Posts

**Leo**  
The Leo Ring  
The Star Regulus  
Leo and the Quasars  
Going Deep in the Constellation Leo  
Leo  
Leo and "The Lion King"  
The Rain Dragon  
The Lion in the Sky  
Pliny on Leo  
The Yellow Emperor  
Hercules and the Lion

**Taurus**  
Taurus the Bull  
Aldebaran, the 'Eye' of the Constellation Taurus  
The 'Raining Stars' of the Constellation Taurus  
The Sacred Bulls of our Ancestors  
The Two-Sided Bull  
The Bull of Heaven

**Gemini**  
U Geminorum, a Dwarf Nova  
Castor and Pollux  
By Jiminy!  
How Close are the Brothers?  
The Twins and St. Elmo's Fire  
Dante was a Gemini...  
The Brothers Gemini

**Andromeda**  
The Royal Family Up in the Sky  
Andromeda's Gorgeous Desert Lynx  
The Ghost of Mirach  
The Original Princess and the Dragon

### Community

Discussion Board  
Astro Calendar  
Show Q&A  
Astronomy  
Books  
Film & TV  
Music

**Illuminations**  
Best of Illuminations  
Illuminations  
Solar Eclipses  
The Sun  
Saturn  
Jupiter  
Venus  
Uranus  
Full Moon  
Mercury  
Pleiades (M45)  
Andromeda Galaxy (M31)  
Mars

### Livecasts

**Upcoming**  
March Equinox and Supermoon Celebration  
The 2019 Total Solar Eclipse

**Recent**  
The Full Snow Supermoon  
Space With Paige: A Three Dimensional Sky  
Total Lunar Eclipse  
Lunar Eclipse Prep with Paige and Paul  
Live from the Observatory  
Behind the Slooh Solar Scope  
Winter Solstice Stories  
Double Feature: The Geminids and Comet Wirtanen  
Lava Worlds to Living Worlds  
Mars InSight Landing  
Full Moon Live Look In  
Monsters' Lounge  
Best Live Feed of the Moon  
Contest on InOMN  
Fomalhaut Live Look In  
Live Look In (Gamma Cassiopeiae)  
Constellation Stories with Helen Avery (Pisces)  
Alpha Piscium Live Look In  
Practical Astronomy with Paul Cox  
Harvest Moon with Helen Avery  
The September Equinox

### Telescopes

Schedule Telescopes  
My Pictures  
All Telescopes  
Chile One  
Canary One  
Canary Two  
Canary Three  
Canary Four  
Canary Five

### About

Pricing Plans  
Slooh Road Trips  
Our Mission  
In the News  
Careers  
Store  
Space Book Club

In the past year I have made 712 reservations and taken 4727 images. These are on Slooh's website in my private pictures folder where they are saved automatically. I have never been attracted to the technical side of astro photography. Merrily clicking buttons on Slooh suits me fine. As an Astronomer member I do get all the FITS files after a mission. Some of the other members are doing some amazing work and producing stunning images. Maybe one day stacking and processing will become more appealing to me.

This year will see some amazing new roll-outs at Slooh. Ambitious plan to "gamify" Slooh to become accessible to teachers and students at schools and colleges, the addition of extra telescopes in a new location in the United Emirates and an upgrade to the existing website are amongst the exciting things that will be happening.

Is online observing the same as being under a dark sky – no. It is less thrilling, I would say, but at least financing/maintaining equipment, rain, wind, dust, dew, humidity, focussing or collimating, are all someone else's problem.

= Carol Botha

You are like a kid in a candy store at SLOOH. Every one of the blue links on the SLOOH page above takes you to page after page of beautiful astronomy.

# Membership:

At Slooh there are two paid membership options and one free account.

By [visiting the website](#) you will be guided to the various membership and payment options. (Some of these may change later this year, but the information here is accurate now.)

I got the following entry-level cost 7 benefits information directly from SLOOH Director Paul Cox:

## SLOOH CREW:

Free account - users can snap images from the live feeds, watch public shows at [slooh.com](#) (but not those designated for "paying" members).

## APPRENTICE membership:

- Cost: \$4.95 per month
- Access: Live Telescope Feeds
- Take Pictures: Unlimited (Includes 'piggybacking' on missions by other members to capture images automatically)
- Control the Telescopes
- *Monthly Reservation Limit* (5 mission reservations per month to control any Slooh telescope)
- Target Objects: *Slooh 500* (Point the telescopes at *Slooh 500* objects, the most popular objects in the night sky)

## ASTRONOMER membership

- Cost: \$24.95 per month
- Access Live Telescope Feeds
- Take Pictures: Unlimited+ (Includes FITS files and 'piggybacking' on missions to capture images automatically)
- Control the Telescopes
- *Unlimited Reservations* (Five concurrent missions booked at any one time. No limit to the total number of mission reservations per month to control any Slooh telescope, and the opportunity to choose the processing preset option for their missions.)
- Target Objects: All (Point the telescopes at any object in the sky, including Slooh 500, major astro-catalogs and by entering celestial coordinates)
- Livecasts
- Community+ (Participate in citizen science research and discovery)
- Many astronomer members consider the following to be the main benefits of an Astronomer account:
  - Unlimited reservations.
  - Reserve missions to any object.
  - Reserve coordinate missions.
  - Select custom processing presets for their missions.



## APPRENTICE

<p><b>Telescope Feeds</b></p> <p>You can watch live feeds of space 20 hours per day, weather permitting! Seven telescopes, including a solar telescope, situated at our flagship observatory, at the Institute of Astrophysics of the Canary Islands, one of the world's top observatory sites, and three telescopes based in Santiago, Chile, offering complementary views of the southern skies.</p>	
<p><b>Livcasts</b></p> <p>Live shows hosted by our team of astronomers featuring eclipses, transits, full moons, asteroids, comets and other celestial phenomena, as well as weekly programs designed to teach you the basics of astronomy, the mythology of constellations and more.</p>	
<p><b>Take Pictures</b></p> <p>You can make a record of your exploration by taking pictures while watching live telescope feeds, which will be saved in your "My Pictures" gallery, as well as have images automatically captured for you.</p>	
<p><b>Telescope Control</b></p> <p>Point any Slooh telescope at any of the Slooh 500, the most popular objects in the sky. You can schedule any of the telescopes up to 5 times per month from our automated interface which will select the best time and telescope to see whatever you choose from our list of targeted objects.</p>	
<p><b>Community</b></p> <p>Learn from experienced members of the community who share know-how and diverse perspectives about what is "out there". Collaborate in citizen science for NASA and read illuminating blog posts relating to what you see in the sky.</p>	

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<p><b>Telescope Control</b></p> <p>Point any Slooh telescope at any object or at any coordinate in the night sky, no limit per month, but limited to 5 at a time. You can schedule 5 or 10 minute "sessions" and configure imaging parameters and filters depending on the selected target.</p>	
<p><b>Community</b></p> <p>Learn from experienced members of the community who share know-how and diverse perspectives about what is "out there". Collaborate in citizen science for NASA and read illuminating blog posts relating to what you see in the sky.</p>	



### SLOOH AWARDED GRANT FROM NATIONAL SCIENCE FOUNDATION

The Phase One SBIR Grant supports the expansion of the platform teaching people to explore space. Slooh plans further gamification of the experience with a series of quests designed to engage new explorers.

[Learn More](#)



## CLASSROOM K-12

### ARE YOU A SCHOOL TEACHER OR ADMINISTRATOR?

Slooh Classroom teaches 4th through 8th grade students how to explore space via a network of online telescopes. Click to learn more about this exciting new product launching in the fall!

[Learn More](#)



### ARE YOU A COLLEGE ASTRONOMY PROFESSOR?

Slooh AstroLab offers college astronomy students a hands-on space lab using a network of online telescopes to gather images of thousands of celestial objects and analyze the data. Click to learn more about AstroLab.



### INTRODUCING ASTRONOMY CLUB FOR SCHOOLS

Slooh's innovative new product allows students to form and manage their own astronomy clubs while learning to explore space via our network of online telescopes.

**March Equinox and Supermoon Celebration**

This month presents us with the final Supermoon of 2019 and the third Supermoon in a row. It has been only a month since the last and the largest, seen together in February. Two months ago we saw the total lunar eclipse which coincided with the January Supermoon. Now March brings us the annual Vernal Equinox within hours of the final Supermoon. We will look through our Canary Islands telescopes on Wednesday, March 20 at 2:00 pm EDT at the setting sun on the Equinox, followed by the rising final Supermoon of 2019.

As we watch the sunset in the Canary Islands, followed by moonrise, Slooh Astronomers Paul Cox and Dr. Paige Godfrey will discuss the particular dynamics involved between Earth and Sun during an Equinox, and what we see as the Moon zooms in at perigee; the closest distance in its orbit around Earth.

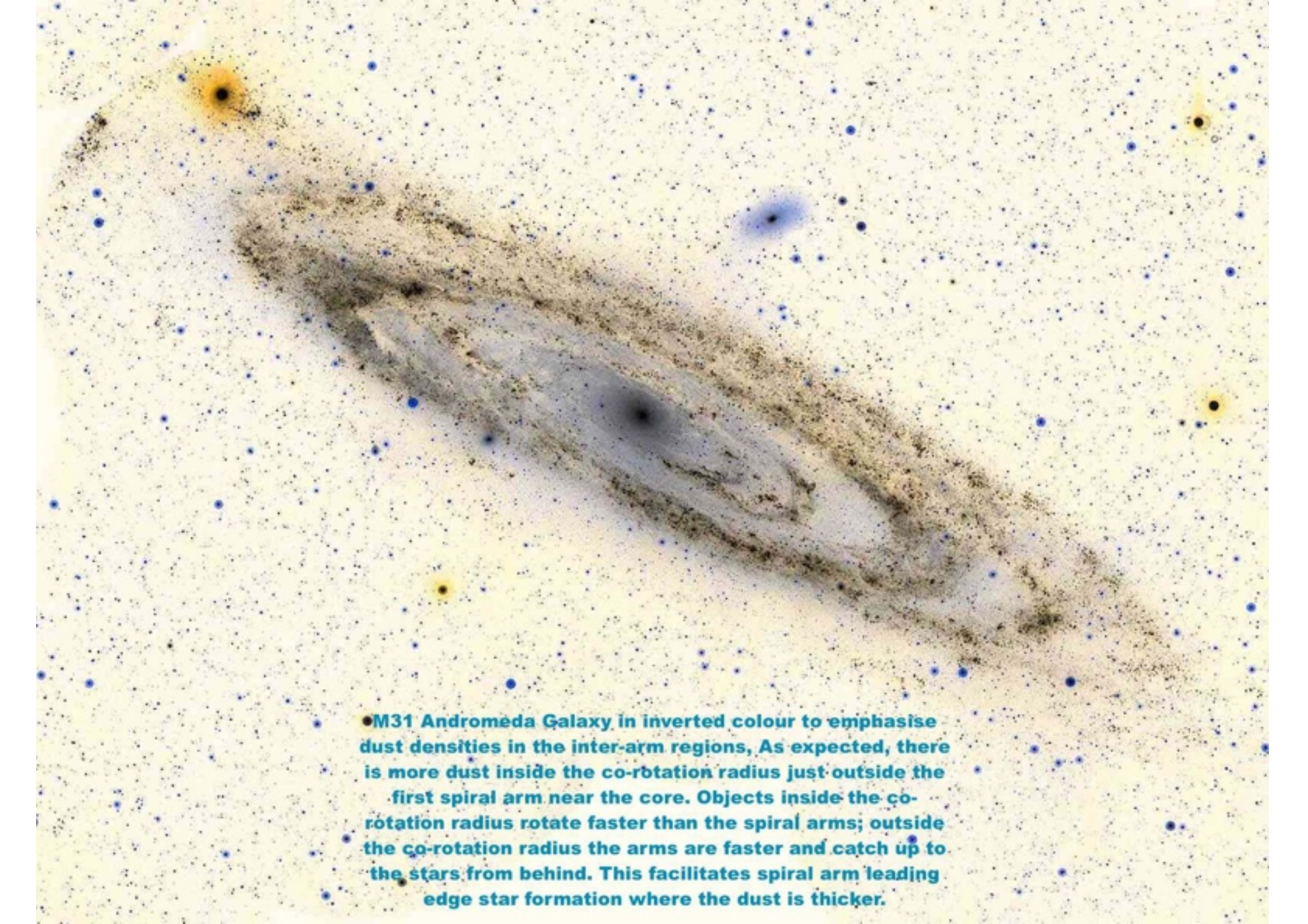
*Ed. Note:* SLOOH is not just looking through fancy telescopes. The staff at SLOOH send information bulletins like this frequently. This one celebrating the arrival of Equinox went out on 20 March this year. The full text of this announcement was a treasury of facts about equinox, a list of upcoming SLOOH events in the next month—and even a beautiful poem about equinox, “An Aeroplane at Stonehenge”.

Read carefully through the online version and you will find only at the very end that the graphic in the above image was made by our very own Carol Botha.

## An Aeroplane at Stonehenge

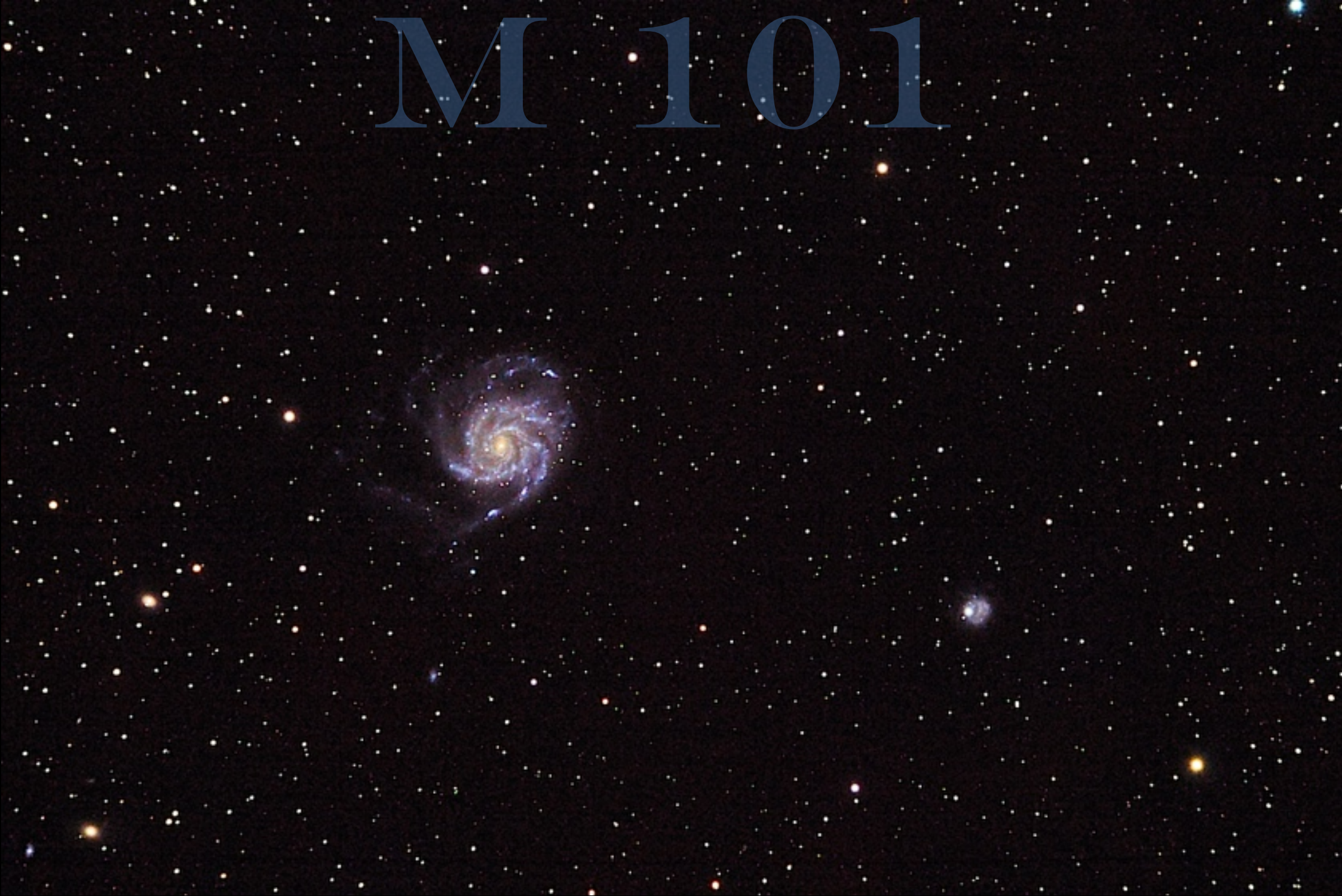
We stood at Stonehenge as the evening fell.  
 A mist had gathered and the reddened sun  
 Glowed like an altar-fire upon the edge  
 Of Salisbury Plain. The aged stones,  
 To whom our thousand years of fear and hope,  
 Of war and peace, were but as yesterday,  
 Merged into the shadows. The solemn night,  
 The mystery, the burden of grey Time  
 Awed us to silence. And then, from the heart  
 Of that age-wonted stillness sprang and grew  
 The iterant throbbing of an aeroplane;  
 And over our Druid world the marvel sped  
 And vanished.

= Edmund Kemper Broadus

The image shows the M31 Andromeda Galaxy in inverted color. The galaxy's structure is clearly visible, including its core, a bar, and several spiral arms. The dust is highlighted in dark brown and black, showing a concentration in the inter-arm regions. The stars are shown in various colors, including blue, yellow, and white. The background is a light yellowish-white with many small, faint stars.

• **M31 Andromeda Galaxy in inverted colour to emphasise dust densities in the inter-arm regions, As expected, there is more dust inside the co-rotation radius just outside the first spiral arm near the core. Objects inside the co-rotation radius rotate faster than the spiral arms; outside the co-rotation radius the arms are faster and catch up to the stars from behind. This facilitates spiral arm leading edge star formation where the dust is thicker.**

# M 101



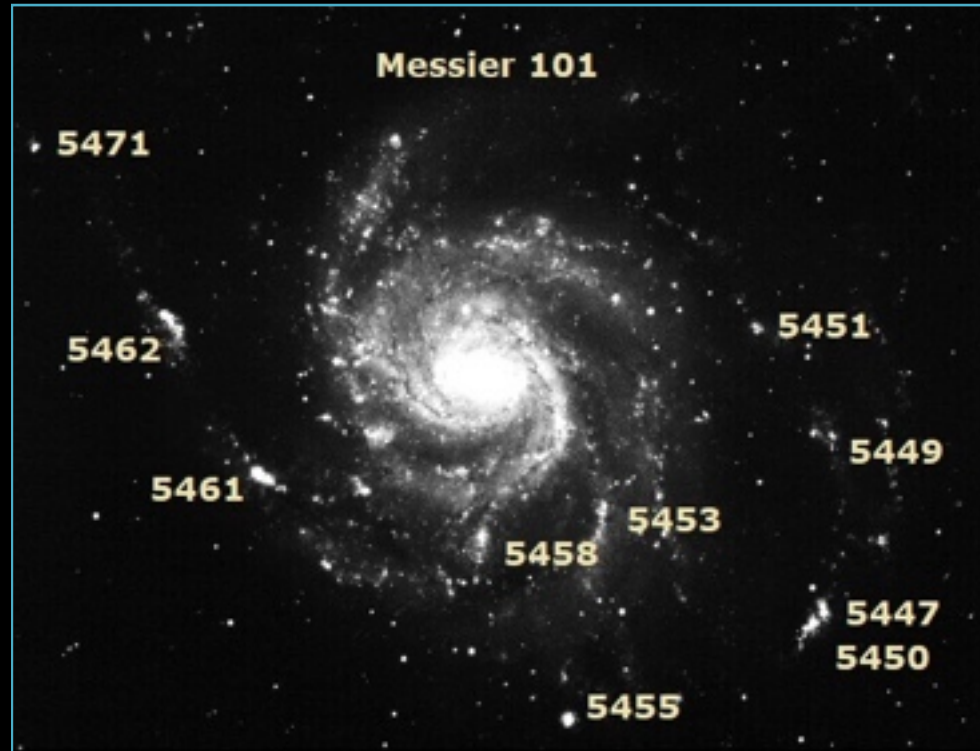
[Watch M101 in simulated rotation seen in optical HST, IR Spitzer, X-ray Chandra, and all 3 combined.](#)

# A deeper look

Magda Streicher

NGC 5457, better known as Messier 101, also catalogued as Messier 102 was described by Charles Messier (1730-1817) as a nebula without a star – very dark and extremely large between the left hand of Böotes and the tail of Ursa Major. Lord Rosse made the first sketch of M101 through his 72-inch Leviathan telescope at Parsonstown in Birr, Ireland. His drawing shows clearly the spiral structure and numerous knots of nebulosity.

Sue French sees the galaxy as a grand Catherine-wheel firework, shedding multiple arm segments, with two prominent arms north of the core which unwrap to the west. Stephen O' Meara admires M101 for its numerous far-flung arms and its distinct asymmetry which makes it readily identifiable. George Kepple describes it as a huge galaxy displaying faint, splotchy spiral arms, curving clockwise around a bright core. The galaxy Messier 33 in the constellation Triangulum is also known as the Pinwheel Galaxy which is slightly confusing.



Hubble's diagram of galaxies offers much information with regard to the appearance of ellipticals, lenticulars and spirals. However, fainter to observe are face-on galaxies, but showing us their faces can provide much more information as well as challenges.

M101 is situated in the northeastern part of Ursa Major near the border with Böotes. It is a Type-SAB(rs) face-on galaxy that shines at a total magnitude of 7.7.

However, this does not mean much because of its low surface brightness. The galaxy appears merely as a large roundish haze with a small, brighter inner section. It harbours ten NGC objects than can be sniffed out on its surface, providing a challenge but also an opportunity for real deep sky study. At a distance of 20.9 million light-years from earth it has about a trillion stars – ten times the number in our Milky Way.

M101 is noted for its large population of HII regions, many of which are bright and usually associated with enormous clouds of high density HII molecular hydrogen gas. HII regions are ionized by large numbers of extremely bright and hot young stars which are capable of creating hot superbubbles.

The brightest double piece of nebulosity is the diffuse nebula listed NGC 5447 and NGC 5450 that ride in the outer south-western arm of M101. The challenge here is to continue north in this arm section to find the diffuse nebula NGC 5449, which can give the impression of two faint, out of focus stars. A few arc-minutes further north brings to light two really faint stars which lead the way to another nebula NGC 5451, a whisper of a lookalike fuzzy star. Averted vision is a good tool to use in this case.

In the southern inner arm section and halfway to the nucleus of M101 lies the elongated NGC 5453. This is perhaps the most difficult one to spot. NGC 5458 just to the east is an elongated piece of dust, so to speak. Perhaps easier is the brighter round spot of NGC 5455 on the southern edge of M101, which settles easily in this hazy blanket of gas and dust. Two similar and slightly brighter nebulae, NGC 5461 and NGC 5462, are situated in the outer eastern arm which spirals out with a dark void between this arm and the denser inner part of the galaxy. The surprise of M101 is the bright roundish star-forming knot NGC 5471 on the far north-eastern edge of the spiral arm, which can easily be mistaken for satellite galaxy.

However, In the surrounding area, a few galaxies can be picked up but the closest companion to M101 is NGC 5477. It is situated less

than 10' towards the north-east. Half a degree south is NGC 5474 another face-on distorted galaxy that might be easy to spot and which shines with a magnitude of 11. Trailing north of M101, is the galaxy NGC 5473, only a drop of haze. Three more very faint galaxies are situated 22' further north-east, NGC 5484, NGC 5485 and NGC 5486, very similar in appearance. A really thin, edge-on galaxy is NGC 5422, the most northerly galaxy.

Messier 101 was actually discovered by Pierre Méchain, the co-worker of Charles Messier, in 1781. Messier added it to his catalogue of 110 objects later that year. The controversy around Messier 101 and Messier 102, which are catalogued as one object, was probably an error on the part of Méchain who later claimed that the observation was a duplicate of M101. Messier's description of M102 stated that it was a faint nebula between omicron Bötis and iota Draconis near a magnitude 6 star. Both Bötis and Draco border the constellation Ursa Major, but the error was that omicron Bötis is quite a few degrees distant from iota Draconis. Méchain's original description of M102 matches far more closely the appearance of the galaxy NGC 5866, situated in the constellation Draco. The Greek symbols for theta and iota could have been mistaken and could have been an error on the part of Méchain at the time. When Méchain tried to verify M102 after the publication was printed, there was no matching description, but NGC 5866 in the constellation Draco is an edge-on lenticular galaxy with a faint dust lane running through the middle with an extended dust halo. It is now considered to be the missing Messier 102.



*Milky Way with crescent moon over Huacachina Desert, Peru, by [Camilo Jaramillo](#) of Colombia.*

# You can hear a scream in space. It just takes awhile.

Dana De Zoysa

A galaxy cluster is no Julie Andrews waltzing through the Alpine tulips with a gaggle of laughing children behind all lustily warbling, “The hills are alive with the sound of music.”

However, contrary to Carl Sagan’s “You can’t hear a scream in space” the universe *does* make and transmit sounds. Sound is simply the propagation of a pressure wave by a medium, and space is abundant with pressure waves of many kinds—large scale supernova shocks, the fractious interacting shells of colliding gas masses, pressure gradients produced by tight binaries rotating rapidly while moving through a gas/dust cloud,

But there’s another way to look at creating sound: *sonification*. The *Geiger counter* invented in 1908 was the earliest and most practical applications of a basic idea: light can be converted into sound; and conversely, sound can be used to create other forms of information, one form of it being light. The medium-into-medium relation, e.g., sound-into-light, was composed into music by experimental electronic musicians like Rainer Wehinger in the 1970s in his interpretation of a piece of electronic music called *Artikulation* originally composed by Gyorgy Ligeti in 1927. (Watch this [YouTube](#) of it.) A vertical line sweeps along Ligeti’s musical “score” and plays a given tone at each symbol. The result is an electronic signal that can be turned into a different forms.

Electronic and digital information share a common property: they can be transformed into almost anything that propagates via pressure density gradients, which we popularly refer to as waves. Examples are sound, light, shapes, sketches, fluids (ocean waves), gases, and even dense solids such as the enormous length-to-width ratios of railway tracks.

While the soundscape that Mr. Wehinger dreamed up is an acquired taste at best, if you analyse the way it’s done, you can see where NASA got their idea. The good folks at NASA *sonified* a Hubble Telescope image of a remote galaxy supercluster into music. (Whether it is music to *your* ears is another matter.)

On 9 March 2019 NASA’s Jacinta Bowler reported in [ScienceAlert](#)



Source: [NASA Hubble](#)

The Universe is a wondrous place, full of vast numbers of planets to explore, unsolved mysteries, and even superbubbles blown by black holes.

But there’s one thing that space really isn’t: loud. Without Earth’s densely packed air molecules to help, space would be silent. But that hasn’t stopped NASA from figuring out a way to produce sound in the soundlessness of space. They’ve done it by sonifying the image of a distant galaxy cluster originally taken by the Hubble Space Telescope.

The image NASA used for this project was acquired by the Hubble’s Advanced Camera for Surveys and Wide-Field Camera 3 in August 2018.

The NASA and Hubble teams called this image “a galactic treasure chest” because of the number of galaxies speckled across it.

“Each visible speck of a galaxy is home to countless stars,” NASA explains about the image.

“A few stars closer to home shine brightly in the foreground, while a massive galaxy cluster nestles at the very centre of the image; an immense collection of maybe thousands of galaxies,



all held together by the relentless force of gravity. The image was so beautiful that a few musically inclined NASA engineers decided to sonify it. They devised a method in which different elements of the image produce different sounds.

Stars and compact galaxies are represented by short and clear sounds, while the spiralling galaxies emit more complex, longer notes. Time flows left to right, and the frequency of sound changes from bottom to top, ranging from 30 to 1,000 hertz. Objects near the bottom of the image produce lower notes, while those near the top produce higher ones.

While the result might sound a little eerie at first, the 'sounds' of this picture create a rather beautiful melody, especially near the middle, when the sound reaches a galaxy cluster called RXC J0142.9+4438. One of the composers of this videos pointed out, "The higher density of galaxies near the centre of the image results in a swell of mid-range tones halfway through the video."

That said, one must admit that the soundscape is beautiful, especially while marvelling at the galaxies that made it. The sounds might be "eerie", but most of us will probably agree that as musical composition goes, galaxy clusters are certainly an improvement on [Gyorgy Ligeti](#), [Luciano Berio](#), or [Iannis Xenakis](#).

## Is there a speed of sound in space?

Carl Sagan's notion that you can't hear a scream in space was proposed in an era when astronomers didn't know much about the particle density and temperatures of what he called "empty space". In reality, space is not a perfect vacuum devoid of all mass. It is more accurately thought of as "the thinnest of thins mixed with the not-so-thin thins". Space is now perceived as a vast arena of density gradients comprising many different energies interacting with many different masses. The place is a mess, really, but what a marvellous mess indeed.

The speed of sound in air at sea level mainly depends on the temperature of the air. On average, it is about 343 meters per second (1,125 feet per second). The speed of sound in a perfect vacuum is by definition zero metres per second because there is no medium with which to propagate it. That sound cannot travel in a vacuum is not a theorem since there's nothing inside to theorise.

However, space NOT a vacuum, it is very *very* thin air. The question is whether "sound" can even be defined in space, or to put it more generally, an extremely low-pressure environment. What we call "sound" depends on whether a propagation wave can be transmitted coherently in that environment. The condition for coherent propagation is a wave whose wavelength is much longer than its mean free path, MFP. The MFP is the average distance travelled by a moving particle (such as an atom, a molecule, a photon) between successive impacts (collisions) which modify its direction or energy or other particle properties. Maybe this will help:

Vacuum range	Pressure in hPa (mbar)	Pressure in mmHg (Torr)	Molecules / cm <sup>3</sup>	Molecules / m <sup>3</sup>	Mean free path
Ambient pressure	1013	759.8	$2.7 \times 10^{19}$	$2.7 \times 10^{25}$	68 nm <sup>[2]</sup>
Low vacuum	300 – 1	220 – $8 \times 10^{-1}$	$10^{19}$ – $10^{16}$	$10^{25}$ – $10^{22}$	0.1 – 100 μm
Medium vacuum	$1 - 10^{-3}$	$8 \times 10^{-1}$ – $8 \times 10^{-4}$	$10^{16}$ – $10^{13}$	$10^{22}$ – $10^{19}$	0.1 – 100 mm
High vacuum	$10^{-3}$ – $10^{-7}$	$8 \times 10^{-4}$ – $8 \times 10^{-8}$	$10^{13}$ – $10^9$	$10^{19}$ – $10^{15}$	10 cm – 1 km
Ultra-high vacuum	$10^{-7}$ – $10^{-12}$	$8 \times 10^{-8}$ – $8 \times 10^{-13}$	$10^9$ – $10^4$	$10^{15}$ – $10^{10}$	1 km – $10^5$ km
Extremely high vacuum	$< 10^{-12}$	$< 8 \times 10^{-13}$	$< 10^4$	$< 10^{10}$	$> 10^5$ km

In interplanetary space near Earth, the MFP is about one astronomical unit and the speed of sound is on the order of 10 to 100 km s<sup>-1</sup>. That corresponds to a frequency of about one cycle *per month*. Space screams are very very slow in the skies just above.

In the extremely rarefied vacuum of outer space, the MFP is *millions* of kilometres. Any particle lucky enough to be impelled by an energy-donating entity would have to travel light-seconds before being able to share its energy density information with another particle. That's why space can be so incredibly hot—1 million to hundreds of million K. There's simply not enough particle collision to dampen their kinetic energy. (*Caveat*: It may be hot out there, but don't stick your finger out the space portal to learn just how hot. A finger flash frozen to colder than liquid nitrogen will require a lot of mitten time before you can use it again.)

The interstellar medium nearby is not especially cold. At the moment, our solar system is moving through a cloud of gas at approximately 6000 K. At this temperature, the speed of sound would be approximately  $9 \text{ km s}^{-1}$ . The speed of sound at sea level is approx.  $1000 \text{ km s}^{-1}$ . The note Middle C in space is around 40 octaves lower than the note Middle C on a piano.

So, low-frequency sounds can, and do, exist in space. But how empty is "empty"? We are well aware that space is filled with gas and dust by the simple fact that we can see it in the form of Galactic cirrus or dark clouds (e.g., the Coal Sack) and warm emission nebulae (e.g., Orion Nebula gas). The pressure of outer space can be anywhere between  $1 \times 10^{-4}$  to  $<3 \times 10^{-15}$  pascals (the SI unit of pressure equal to one newton per square meter), which is approximately 0.000145 pounds per square inch.

Assuming for a moment that interstellar space is heated uniformly by the CMB, space will have a temperature of 2.73 K. Most of space is filled with electrons, protons, and neutral hydrogen atoms at a density of about 1 atom  $\text{m}^{-3}$  to 1 atom  $\text{cm}^{-3}$ . This means that  $\gamma=5/3$ , and  $m=1.66 \times 10^{-27} \text{ kg}$ , giving a value for the sound speed  $v_{\text{sound}}$  of  $192 \text{ m s}^{-1}$ .

As a rule of thumb, the speed of sound in a molecular cloud averages  $200 \text{ m s}^{-1}$  integrated across the molecular core and atomic shell of the cloud. Molecular clouds span a vast range from 10 up to  $>100 \text{ pc}$  in diameter and  $10^4$  to  $10^7$  solar masses at densities from 1 particle to 10 particles  $\text{cm}^{-3}$  ( $N_H < 1 - >10$ ). Even in our own galaxy, conditions vary wildly.

"Empty" space is a locale about which one can use extravagant language and not appear melodramatic. Articulate these numbers in everyday language:

Molecular Clouds,  $\rho \sim 10^4 \text{ atom cm}^{-3}$ ,  $T \sim 10 \text{ K}$

Cold Neutral Medium,  $\rho \sim 20 \text{ atom cm}^{-3}$ ,  $T \sim 100 \text{ K}$

Warm Neutral Medium,  $\rho \sim 0.5 \text{ atom cm}^{-3}$ ,  $T \sim 1000 \text{ K}$

Warm Ionized Medium,  $\rho \sim 0.5 \text{ atom cm}^{-3}$ ,  $T \sim 10,000 \text{ K}$

HII Region,  $\rho \sim 1000 \text{ atom cm}^{-3}$ ,  $T \sim 8000 \text{ K}$

Hot Ionized Medium,  $\rho \sim 10^{-3} \text{ atom cm}^{-3}$ ,  $T \sim >10^6 \text{ K}$

Hot intracluster medium (between large galaxy clusters),  $T$  up to  $10^8 \text{ K}$ .

Extravagant? You bet. Sound speed is proportional to  $T^{-2}$  (i.e.,  $\sqrt{T}$ ). Given that the temperature varies over about seven orders of magnitude (minimum about 3 K, maximum about  $10^7 \text{ K}$ ), sound speed varies by a factor of 1000.

Mach velocity (sound speed) plays a crucial role in many astrophysical processes. It defines the time it takes for a pressure wave to propagate a given distance. One example where sound speed is a critical matter is the time scale of a molecular cloud core's gravitational collapse. If the sound crossing time for a gas cloud exceeds the gravitational free-fall time (i.e., the time for a gravity-driven disturbance to propagate), pressure is unable to resist gravitational free-fall and the cloud is irrevocably consigned to the task of creating a compact object, whether a dense dust cloud or a star.

So scream, get it out of your system. Then listen, carefully.

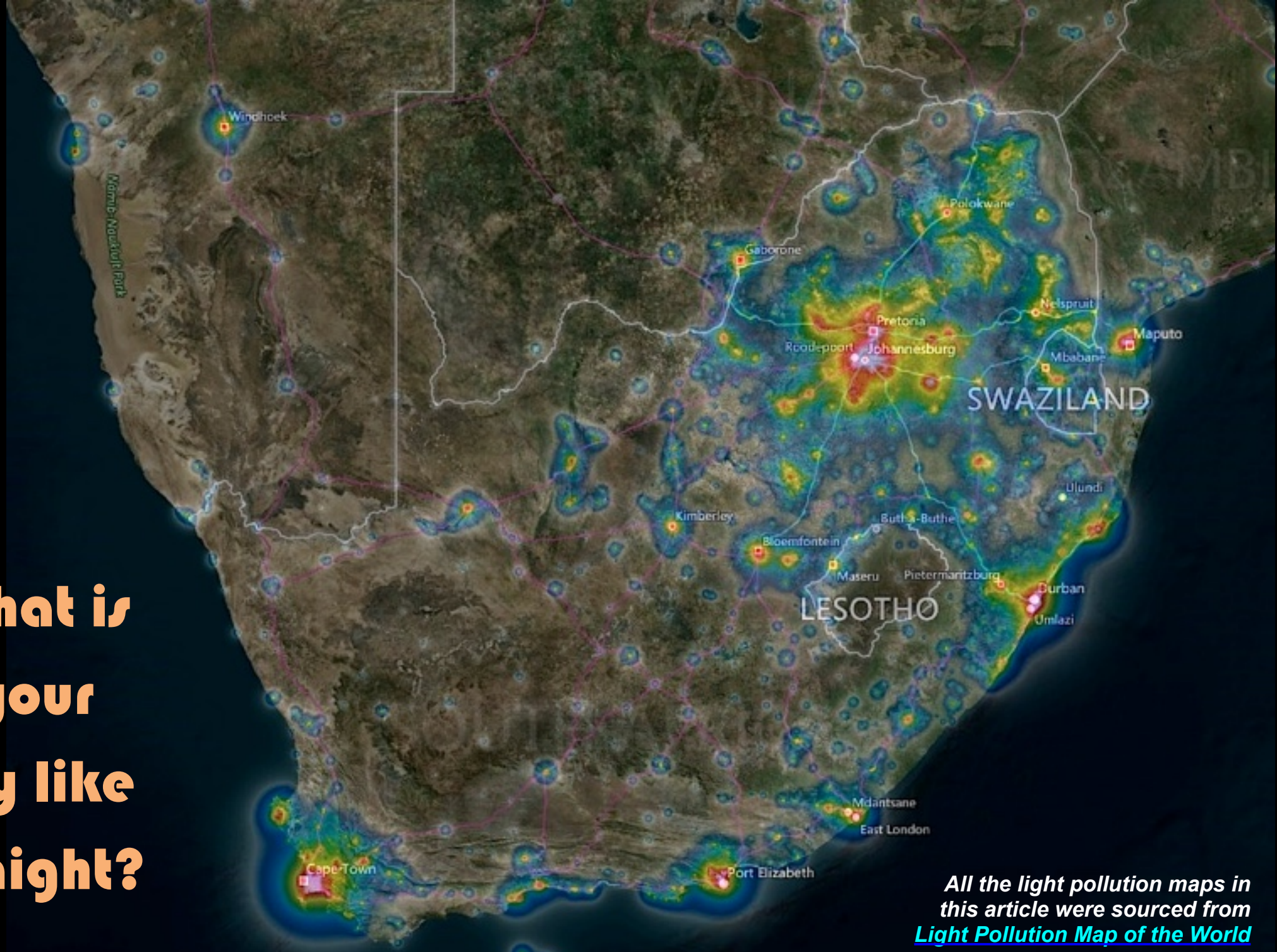
Just don't look at your watch



[www.arcticlightphoto.no](http://www.arcticlightphoto.no)

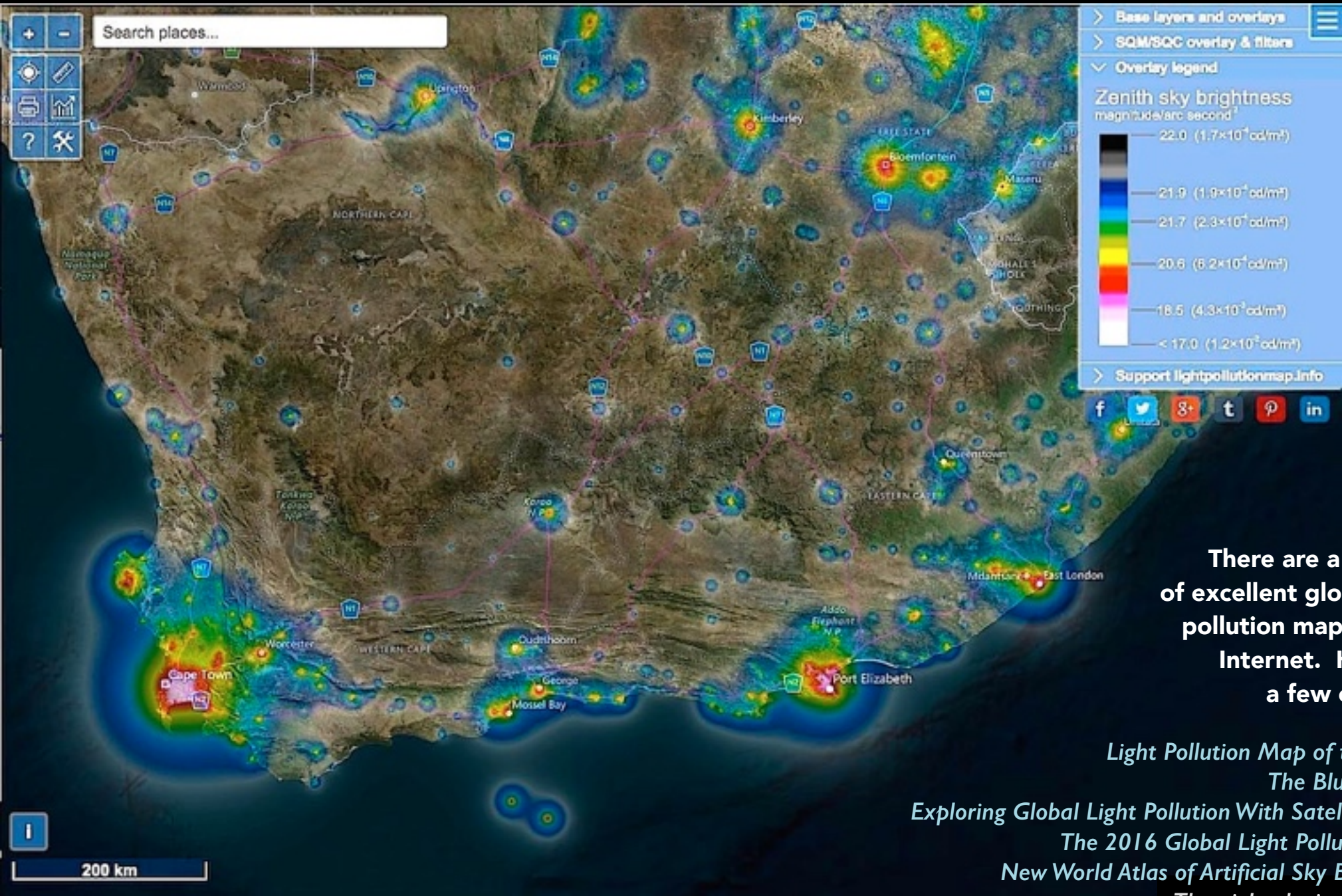
**Aurora and meteor near Tromsø, Norway, October 2012. Source: [APOD image by Ole Salomonsen](#)**

**What is  
your  
sky like  
tonight?**



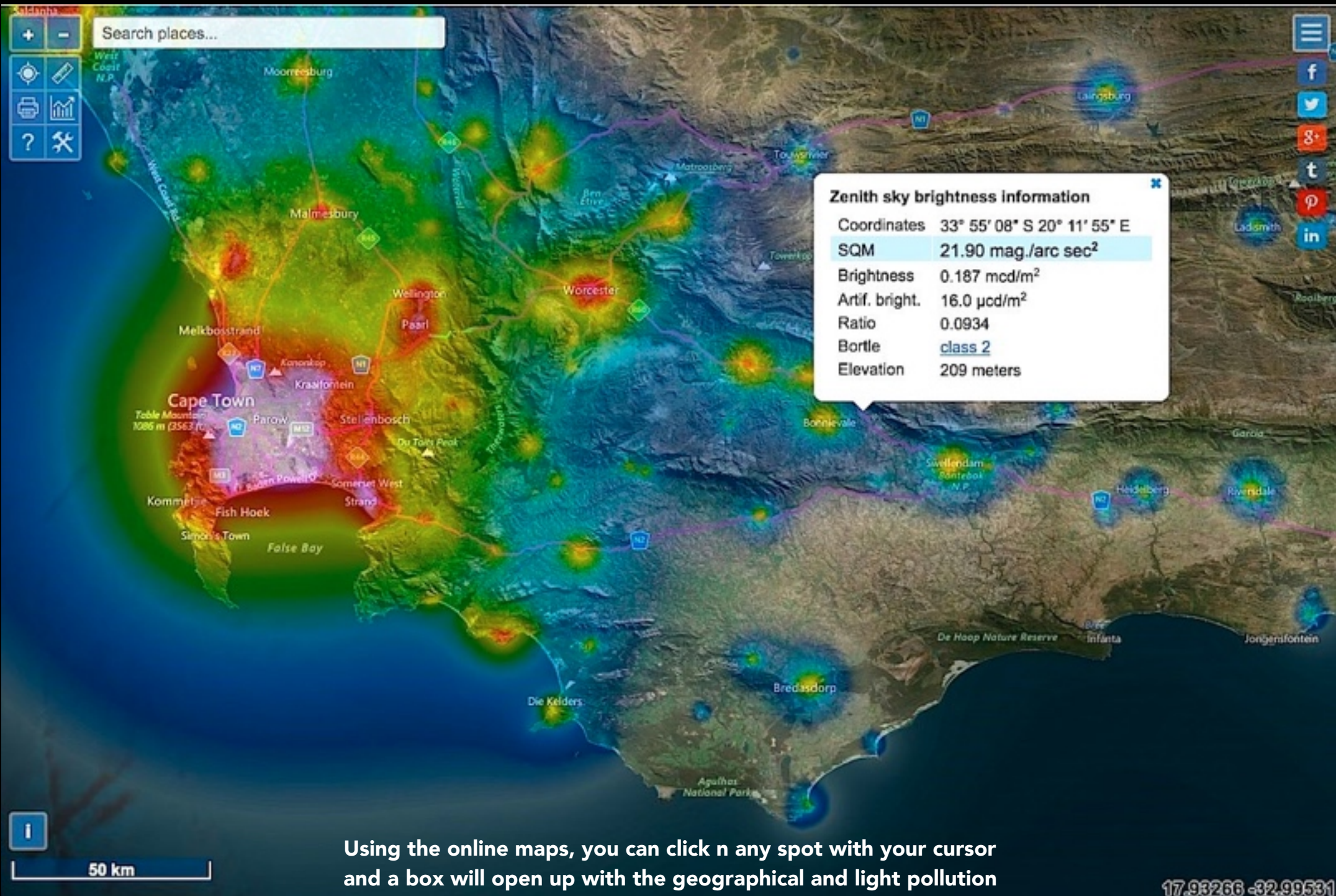
*All the light pollution maps in this article were sourced from [Light Pollution Map of the World](#)*

# This is where to find the nearest dark sky

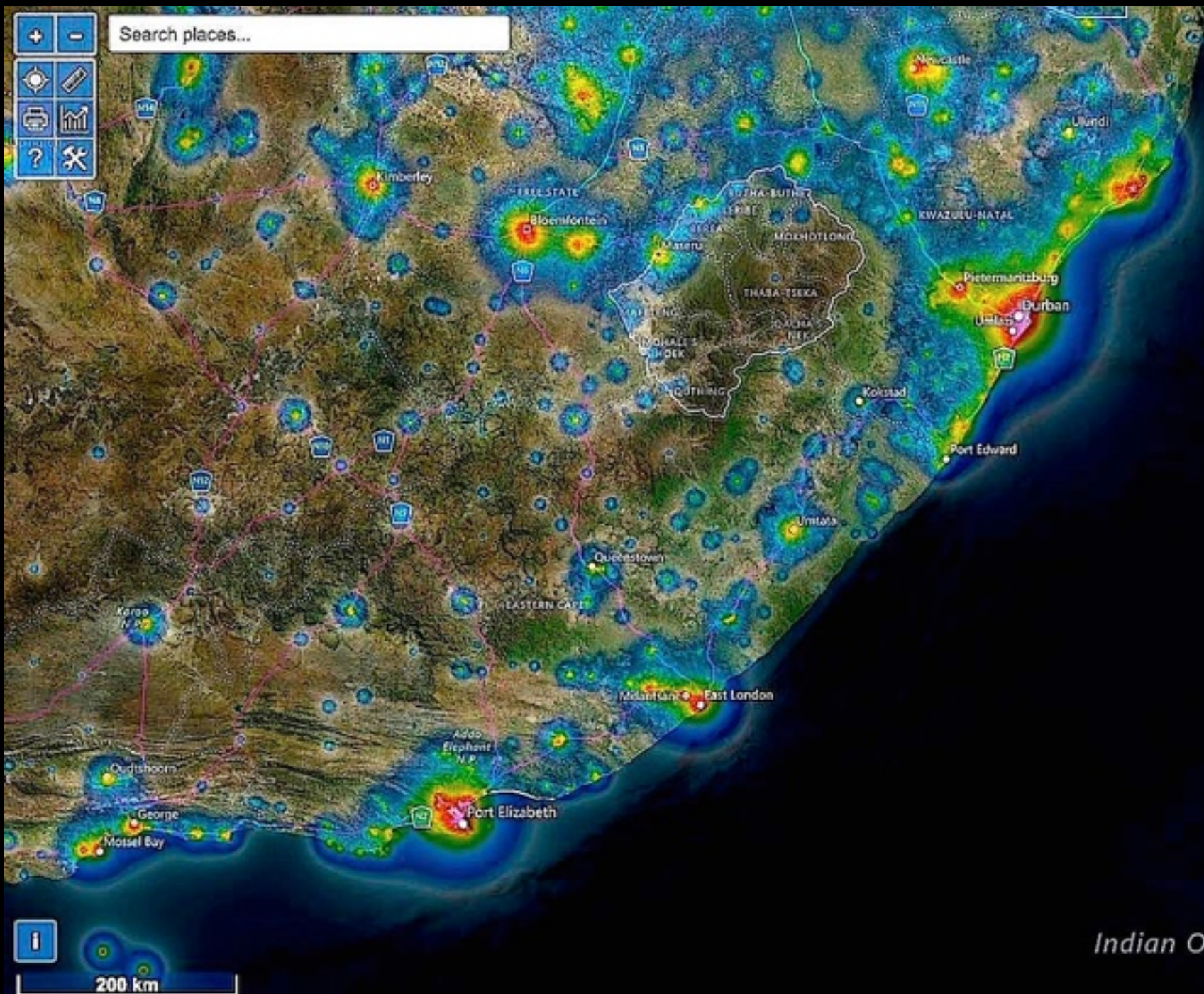


There are a number of excellent global light pollution maps on the Internet. Here are a few of them:

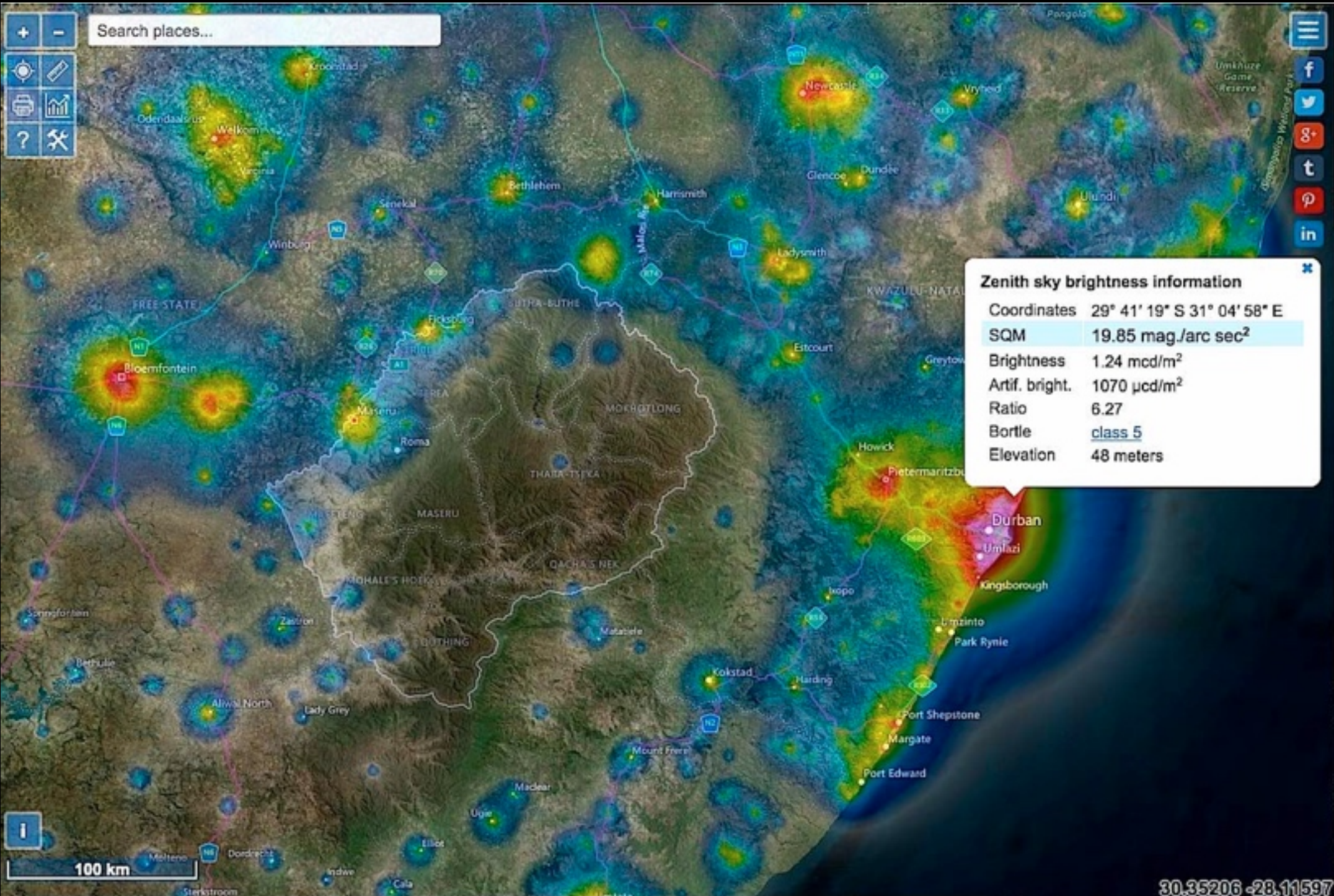
- Light Pollution Map of the World*
- The Blue Marble*
- Exploring Global Light Pollution With Satellite Maps*
- The 2016 Global Light Pollution Map*
- New World Atlas of Artificial Sky Brightness*
- The night sky in the World*



Using the online maps, you can click n any spot with your cursor and a box will open up with the geographical and light pollution statistics for that exact spot on cloud-free moonless nights.

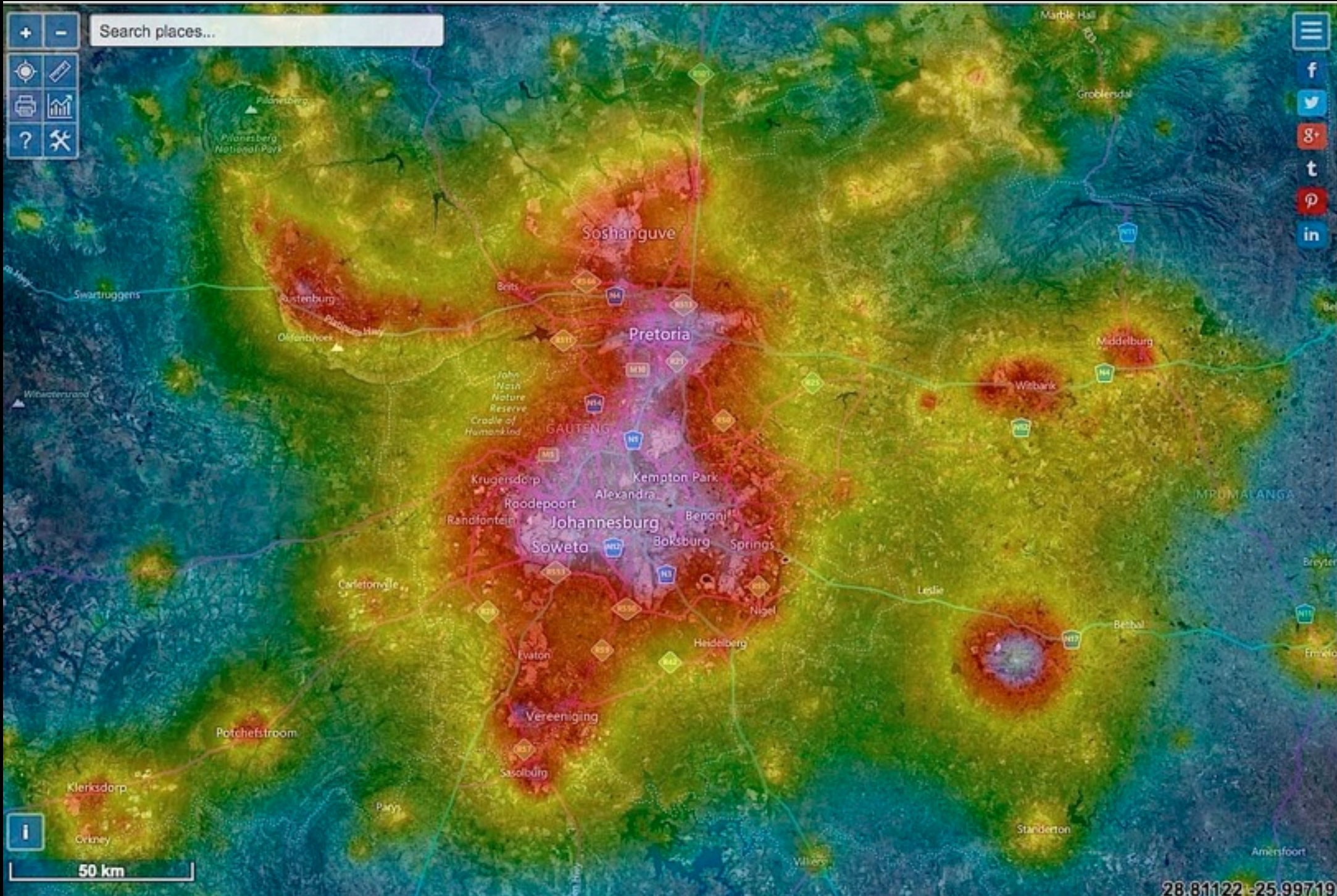


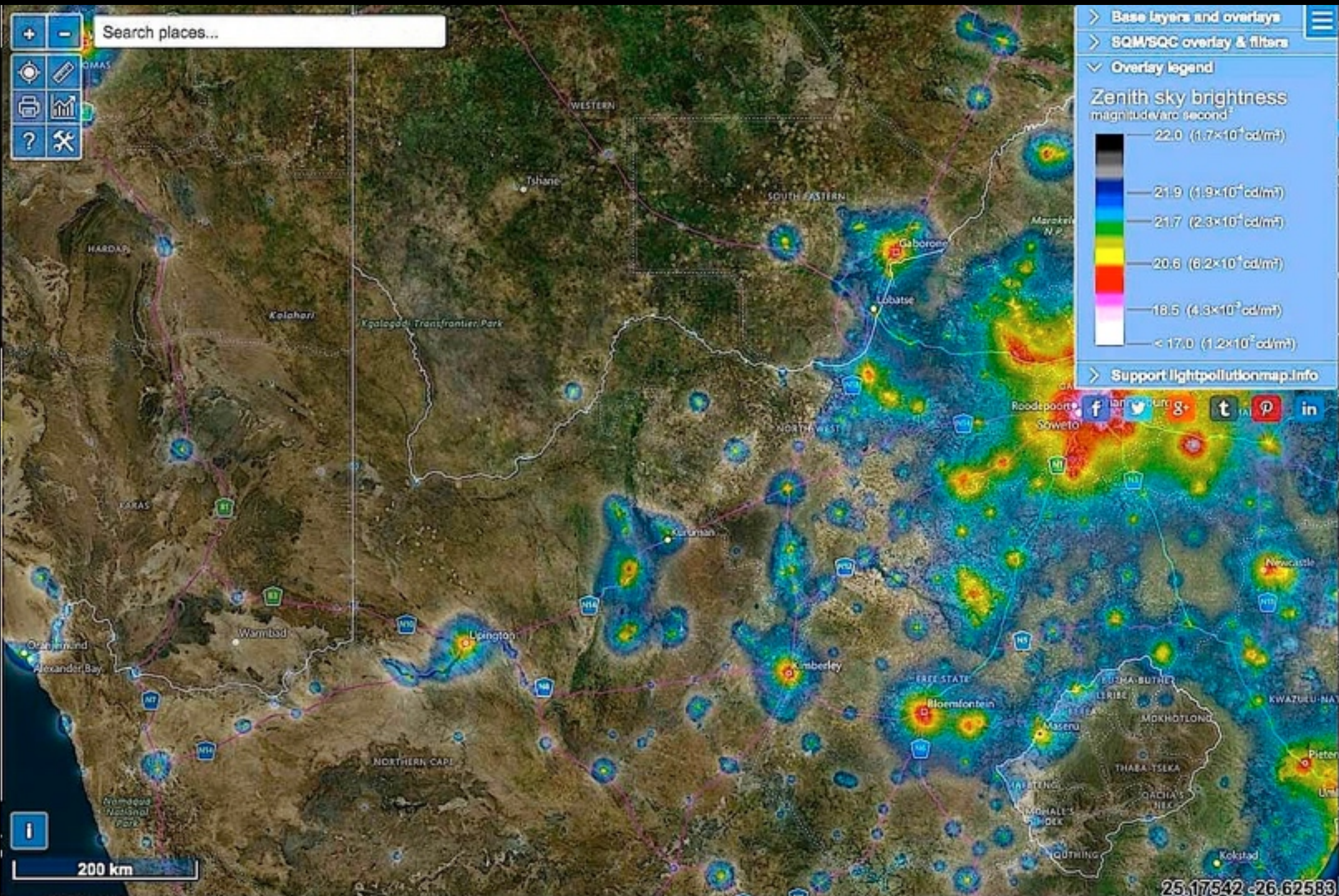
29.47109 -32.68377











# Why we need SKA

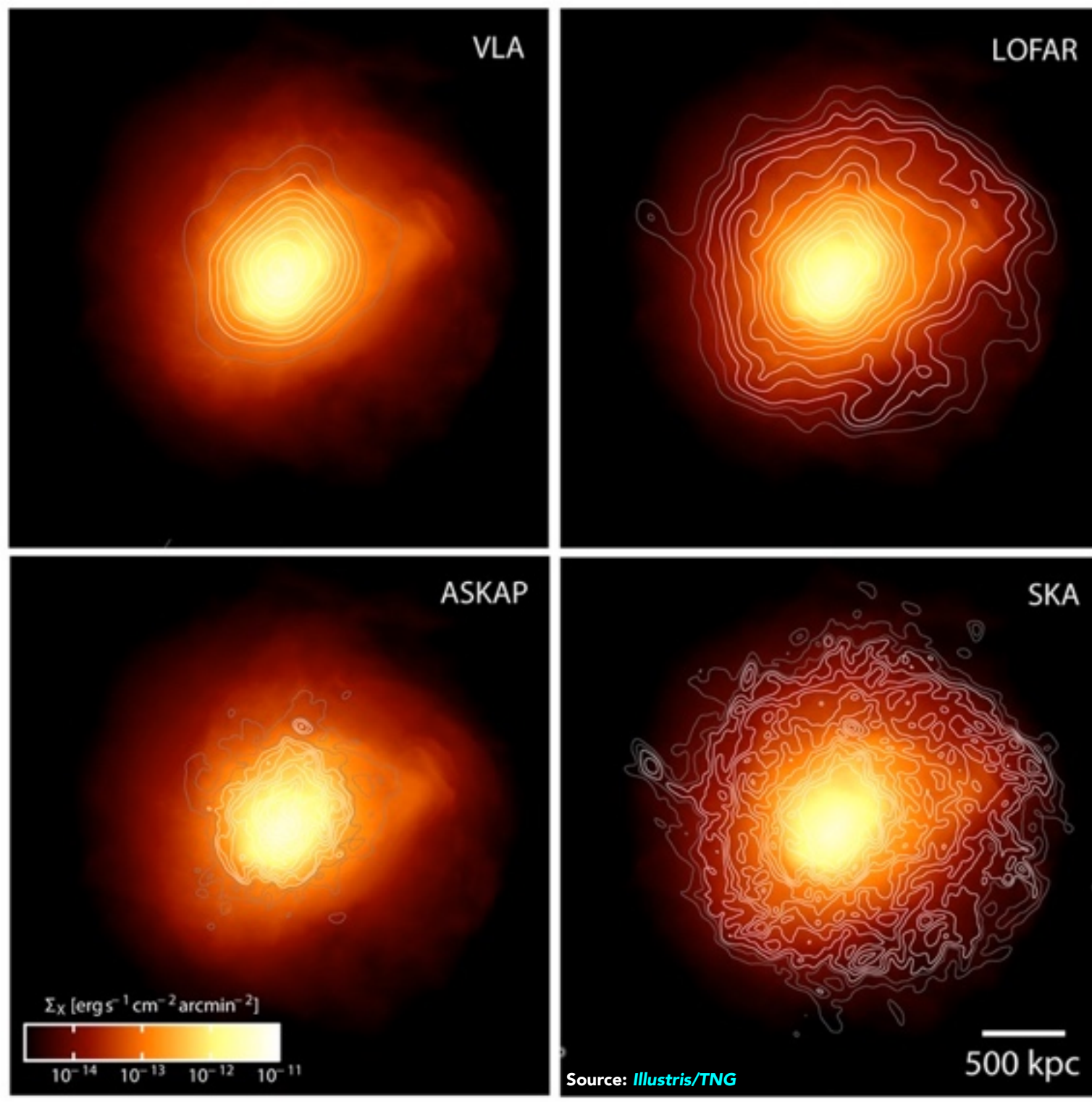
X-ray map (colour) overlain with synchrotron emission contour lines for the most massive halo of the TNG300-1 simulation. The panels are 3.5 Mpc on a side, each of the four representing a hypothetical observation by a different radio telescope.

The Jansky Very Large Array (VLA) comprises 27 antennae digitally combine 351 signals into a single antenna with a variable diameter. Each antenna is a 25-meter radio dish deployed in a Y-shaped array designed for [aperture synthesis](#) interferometry. The angular resolution that can be reached is between 0.2 and 0.04 arcseconds. The frequency coverage is 74 MHz to 50 GHz (400 to 0.7 cm).

The Low-Frequency Array or LOFAR is a large [radio-band](#) array centred in the Netherlands. Signals from 20,000 small antennas in 4 locations are digitised, sent to a central digital processor, and combined in software to emulate a conventional large-diameter single antenna. LOFAR combines signals from separate low-band and high band antennae tuned to 10-80 MHz and 120-240 MHz. (Birr Castle)

ASKAP, the Australian Square Kilometre Array Pathfinder, at [Murchison Radio-astronomy Observatory](#) (MRO) in Australia has 36 identical parabolic antennas 12 metres in diameter which work together as a single instrument with a total collecting area of ~4,000 square metres. ASKAP was designed as a technology test-bed for the [Square Kilometre Array](#) (SKA) presently under construction in South Africa.

SKA, the [Square Kilometre Array](#), will have a total collecting area of approximately one square kilometre. It will operate over a wider range of frequencies than earlier detector arrays. It will be 50 times more sensitive than any other radio-to-mm band telescope and survey the sky more than ten thousand times faster than before.



**If  $1 \times 1 = 1$ , then  $1 \times 2 = 3$ , right?**

*It all depends on how you define your terms.*



*Image courtesy  
of Jerry Ollion*

*Here's how ATMS have  
turned  $1 \times 2$  into 3.*

**$1 \times 2 = 3-D$**

# Welcome to the exotic world of bino-builds



Like almost all bino builds with tracking ability, this standard twin-13 inch is equipped with ServoCat and Argo Navis. If this massive dobsonian system looks overbuilt, that's because it is. The owner wanted the option of scaling up to a twin-18 inch.



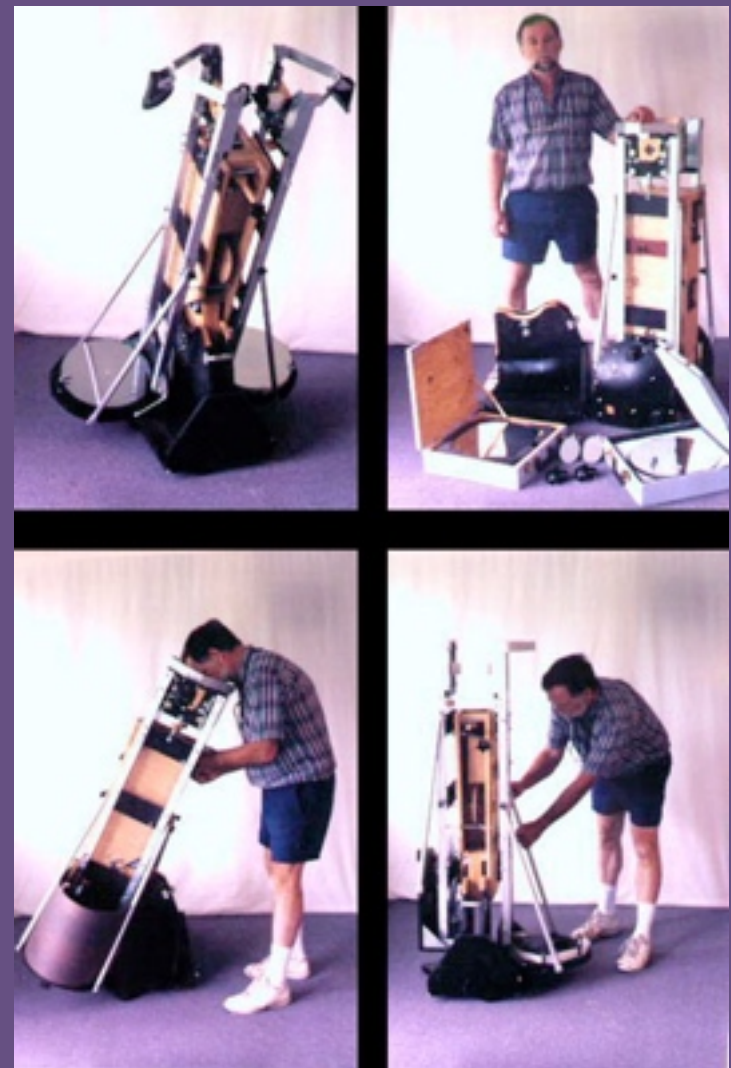
Here is an example of two identical 8 inch f/6.0 mirrors. This system comes has the light-gathering ability of a single 11.8 inch scope, but eliminates the need to chase the eyepiece all over the sky.

At moments like this, Arie Ott really regrets not having identical twins!



**Bruce Sayre's 14-inch column-truss bino features:**

- 2.5x the cost of a single mirror scope
- Base weighs 50 pounds
- Half an hour setup/takedown using only thumb screws
- InterPupillary Distance (IPD) adjustment with a single knob
- Sub arc-second binocular alignment through 70% up and down vertical altitude
- Scope control using iPhone running Sky Safari Pro
- CAD designed
- 8022 extruded aluminum mirror-frame / column-tube construction
- Uses 3D printed parts



This Dave Trott portable 13 twin Dob reverses the idea of the fork mount by putting the fork tines in the centre, not around the outside. This is not as stable as a traditional Dobsonian, but is good for frequent transport to the field. This bino took about 20 to 30 minutes to assemble and collimate. The larger the system the more difficult the setup and collimation. In a comparison test, this bino was superior to the performance of a single 17.5-inch scope. See Dave's [full-length article here](#).

## Bino-man meets Batman, French-style.



Jacques Civetta's 18-inch bino-build,

- The whole bino weights 45 kg, its heaviest elements being the mirrors (14kg each).
- It takes about 20 minutes to get into action including collimation adjustment.
- [Learn how Jacques did it here.](#)



# Binoscopes are a lot of equipment and a lot of money. Why bother?

Edited down from a full-length article by Jerry Olton [available here](#).

The renowned astronomy columnist Phil Harrington inevitably ends his columns with, 'And remember that two eyes are better than one'. And he is not alone. I paraphrase some remarks made by observers who are lyrical about observing with a binoscope:

...watching the globular cluster almost made me tumble from the ladder...  
...it feels as if I approached the doorstep of the cluster with a spaceship...

Well, this sounds like a revolution in the visual observing of deep-sky objects, right? But what facts support these claims? What happens when signals are received separately by two eyes and processed by the brains? And 'how much better' is it to observe with two eyes instead of one? It turns out that there are multiple complex processes that play a role.

## Signal to noise ratio

Using both eyes instead of only one increases detection by a factor of 1.41. A factor of 1.41 means a 41% improvement in detection ability. This in turn translates to a light-gathering throughput of a telescope 19% larger in diameter.

The most important consequence of this is better signal to noise ratio, which in turn leads to a darker perceived sky background. What does this mean? A stimulus that is not originating from an astronomical object (for instance 'light noise' from light pollution) could be interpreted by one eye as a bona fide signal. But the chance that such random noise signals hit

two eyes simultaneously and reach the brains is very small indeed. In other words, when looking with two eyes, the brains do have to suppress much less background noise created by light pollution. And this automatically translates itself into a darker sky background, even in my light-polluted hometown. This phenomenon is in particular relevant for the observation of very faint galaxy halo's or arms. Within these faint, extended objects many more details become visible and the contrast within the objects is greatly enhanced.

## 3D and the optics of chromostereopsis

Stereopsis is the ability see depth. An object viewed by each eye from a slightly different angle creates the 3D effect. The closer the object is, the greater the 3D effect. Stars are so far away that the angular distance of a cone one meter wide and 100 light years long is vanishingly small. How does the eye create a 'real' 3D effect with a binoscope?

The name for this effect is stereopsis. But astronomical objects are so distant that there is no such thing as parallax and consequently no 'real' stereopsis.

Moreover, there is a related phenomenon called chromatic stereopsis or chromostereopsis. This is caused by the slightly different refraction angle in the eye lens of red versus blue light. Red and blue light focus in a slightly different place on the retina. This effect is different for each eye. Red stars appear to stand a tiny bit closer than blue stars. When looking through a binoscope, chromostereopsis creates an illusion of depth, even though it is an illusion.

## Enlarged field of view

Binoscope users maintain that you can achieve larger fields of view with a binoscope in comparison with a standard monoscope. Indeed, looking through a binoscope, this is a beautiful effect that is immediately obvious. But why is that? If you take the example of my 2 x 13 inch binoscope with f/5.0 mirrors, the use of two 10 mm Televue Ethos 100° AFOV eyepieces delivers a 165x magnification and a 0.61 degree true field. (The Moon pole-to-pole at 165x is indescribable!)

Suppose this binoscope has an approximate equivalent of a 18 inch mono-telescope, also being f/5.0. Now the 10 mm Ethos would deliver a 225x magnification and a 0.45 degree true field, to achieve a 165x magnification and a 0.61 degree true field means the 18" needs to be f/3.7. Since this creates a massive amount of coma, a coma-reducing Paracorr has to be part of the optical train. Paracorr's deliver an effective f/0.83. Hence the mirror needs to be an even shorter f/3.2 for these same magnification and true field. Guess how much two such steep mirror are going to put a dent in your retirement savings?

There is another aspect here that is rarely addressed. In humans, the horizontal binocular visual field is 120 degrees. But there is an additional 45 degrees monocular field on each side of the binocular field. So, there is a total of a 90 degrees field that is non-binocular; indeed, it can be seen by looking with two eyes, then looking with one eye only. Even though you cannot encompass the entire 120 plus 90 degrees at one glance, you will observe it peripherally. Together they add to the feeling of being present in the picture. The choice of eyepieces is important here: with two 50° AFOV eyepieces, you will just see the field stops. But the effects are very obvious when two eyepieces with an apparent 100° field.

## Image-merging

The use of a binoscope involves more complex features such as the need to merge the images. One way to achieve that is by very slightly moving the primary mirrors in relation to each other. In my telescope design this is accomplished by turning the long aluminium rods that are attached to the mirror cells. See for elaborate explanations and discussion the Article Merging of the Images.

## Interpupillary distances

Since different observers have different distances between their eyes, a binoscope must have a mechanism to change this so-called interpupillary distance (IPD). Principally, two solutions are available. One is to use two sets of focusers, and the other is to construct so-called tunable tops. With tunable tops one or two upper secondary mirror cages are rotated around their axis. The advantage is that the length of the lightpath does not change, so no re-focusing is required when different people use the binoscope. However, there often remains some residual slop in the system, which easily results in separation of the images. I found this last aspect more negative than just some re-focusing. After extensive use of both approaches I prefer and use the four-focuser solution.



## What about different focal length main mirrors?

Do the twin mirrors in a bino need to be exactly the same focal length? Is a few millimetres difference OK? What about 2 or 3 centimetres difference?

It turns out that the difference in field isn't as critical as the difference in magnification between the two images. Can you merge two images into a binocular view if one of the primary mirrors is slightly longer? If one mirror is 64 inches and the other 63, using two 14mm eyepieces, you'd get 128x & 126x. Tolerances for this are very tight and can't be fixed by shifting one mirror forward or backward in the tube. Some technical discussions on this conclude that says magnification differences of less than 1% are not significant, at between 1% and 3% differences appear in the outer field that can be ignored — one workaround is Plössl eyepieces with  $\sim 50^\circ$  AFOVs, which is fine for compact objects. If one eye sees a globular cluster at 100x and the other sees it at 102x, the stars in the outer part of the cluster will differ by 1/50 of the total field diameter. Between 3% and 5% magnification difference (e.g., 100x -vs- 105x) binocular vision begins to degrade within the 20% central zone. Over 5% one loses binocular images altogether and you seem to be looking at a mess instead of stars.

One solution to this is inserting two Barlows into the optical train, then moving one of them slightly forward or reverse until the image improves. But that pretty much eliminates wide-field work and who wants to go through the night without gazing fondly at the Orion or Carina Nebulas?.

Stereo resolution (perceiving distances) is linearly related to magnification differences.

## A good club project: two identical OTAs that can be bino'd when desired

Bino systems aren't practical for public star parties. First-timers often don't know where to look in the eyepiece, and an off-centre view is unsatisfying.

People often try to re-focus, even when the focus lock is tight. By nature binos require adjustable-height viewing chairs. Binos are sensitive to being bumped. A large number of people sliding into and out of an observing chair translate to constant owner re-focusing. People have wide differences in interpupillary distance, so the focusing system has to be re-adjusted for every viewer.

Some clubs have sorted this problem by building two nearly identical single scopes for public events and when they want an experienced-viewer club get together they mount the pair on a custom trunnion. [Dave Trott's excellent bino web page](#) shows how a twin 13-inch sonotube telescope can be reconfigured to a bino using a custom trunnion his club designed and built.

If you are a refractor buff, see Dave's excellent page on his [home-made refractor sets from 60mm to 4-inch](#). Lots of detailed instructions and pictures here.

Want something in the 6-inch range. Dave's detailed 6-inch f/6 build is inspiring — and as step-by-step as you'll find anywhere. This would be another great club-synergy project; everyone can get into the act with their own special talents.



## Binoscopes versus binoviewers

Is observing with a binoviewer the same as observing with a binoscope? At star parties, there are rather few if any binoscopes around, but lots of good quality binoviewers. Why bother to make a complex binoscope when you can just stick in a binoviewer in an existing, large mirror telescope? Some of the plusses and minuses are these:

Binoviewers are a lot cheaper than a binoscope. You have to buy two identical copies of every item in the optical path.

Binoviewers feed light to both eyes at once, which makes deep sky observing easier – you can throw away those sinister-looking eye-patches and black hoodies.

However, binoviewers split the light signal in two with half-silvered mirrors or with right-angle prisms. This halves the total luminosity entering each eye. A small amount of light also lost because of two mirrors or prisms in the light train. The result is reduced contrast, which affects shadow details in planets and faint tracers in extended nebulae. Binoviewers work best on low contrast bright objects such as planets and the Moon. The high contrast seen with a binoscope is reversed in a binoviewer.

Probably due to a smaller increase in the level of contrast, observers who have compared binoviewers with a binoscope confirm that views with a binoscope are much more lively than with a binoviewer, most noticeably with deep-sky objects such as galaxies and faint clusters.

The actual fields of views in a binoviewer are reduced because binoviewers insert a low negative-power Barlow lens in the optical path to compensate for the light cone's being extended backward by the prism assembly.

## Find out more here

Peter Abrahams' [The History of the Telescope and Binocular](#) is the most comprehensive single-source reference base in the literature. Literally hundreds of links to all things telescopic.

Bino-Techno is a Japanese original equipment manufacturer (OEM) with a [very detailed website devoted to the optics side of bino-viewing](#), including many dissolving-fade images that show how components work together optically and mechanically.

[Jerry Olton 12.5-inch bino build](#) with detailed construction images.

[Jacques Civetta's elegant 18-inch bino](#) with custom-formed fibreglass OTA & mirror box (featured above); one of the most beautiful telescopes around.

[Jeorg Peters insightful ideas and methods](#) of building a 28-inch slumped-glass binoscope, incl software programmes for analysing surface aberrations & where to place spot-correcting tools.

[The Bolton Group's 200 mm Minimalist Build](#)

[Analog Sky's detailed analysis](#) & design of collimation & eyepiece-placement issues.

[Science sense and nonsense in bino viewing](#) (a Cloudy Nights article).

**The Wolf-Rayet star WR34 in Carina almost frantically shedding its outer envelope gas in a vain effort to avoid the inevitable. In several thousand years it will go supernova.**



# Heartwarming astronomy tale of the year









Marina Thévenot takes a selfie.

## THE ASTROPHYSICAL JOURNAL LETTERS

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### A 3 Gyr White Dwarf with Warm Dust Discovered via the Backyard Worlds: Planet 9 Citizen Science Project

John H. Debes<sup>1</sup> , Melina Thévenot<sup>2</sup>, Marc J. Kuchner<sup>3</sup> , Adam J. Burgasser<sup>4</sup> ,  
Adam C. Schneider<sup>5</sup> , Aaron M. Meisner<sup>6,13</sup> , Jonathan Gagné<sup>7</sup> , Jacqueline K. Faherty<sup>8</sup> ,  
Jon M. Rees<sup>4</sup>, Michaela Allen<sup>2</sup> [+ Show full author list](#)

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[The Astrophysical Journal Letters, Volume 872, Number 2](#)

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[+ Article information](#)

# Teen-ager discovers unique white dwarf

Hi everyone. I am Melina Thévenot, a volunteer of the Backyard Worlds: Planet 9 project from Germany. Here I want to tell you a bit about how I discovered an unusual white dwarf and how the researchers uncovered that it is not only unusual, but also cool.

## How did I discover the white dwarf LSPM J0207+3331?

As a volunteer of the Backyard Worlds: planet 9 project, I spent a lot of time searching for brown dwarfs. The Gaia Data release 2 was my favorite survey for the search of brown dwarfs. I uncovered probably several hundred new brown dwarf candidates that move in wiseview with the help of three other volunteers: Katharina Doll, Hugo Durantini Luca and Peter Jalowiczor.

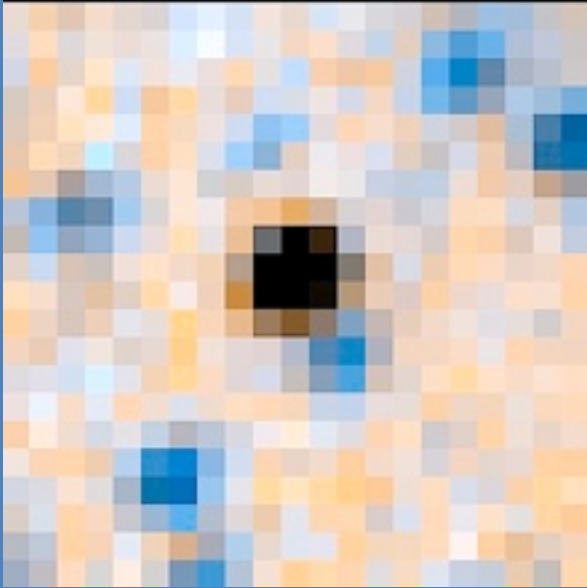
While improving my search I noticed something about brown dwarfs in the Gaia catalog: some good sources don't have color information in Gaia DR2. This is a problem, because I relied on a color-cut. To check if I missed any good T-dwarf, I decided to use Allwise to find sources with high infrared excess and the high parallax measurement in Gaia DR2. In the resulting list I could find fake sources that did not move in Wiseview, T-dwarfs (distance 5 to 10 parsec) and one source that does not belong in this list, LSPM J0207+3331.

Was this yet another false source? I could have ignored it. I am glad I checked the movement. Compared to the background objects it is moving and in PanSTARRS you can see a blue source.

This source is LSPM J0207+3331. At this time I still had no clue what it could be. I did need some days to think about it. After checking the position in a HR-diagram I knew that it was a white dwarf with large infrared excess (Allwise  $w1-w2=1$ ). I guessed that this excess comes from a circumstellar disk. Time to loop in some other volunteers, who are advanced users of Disk Detective.



2014.0 - 2017.6



See blink comparator parallax image of LSPM J0207+3331 [here](#).

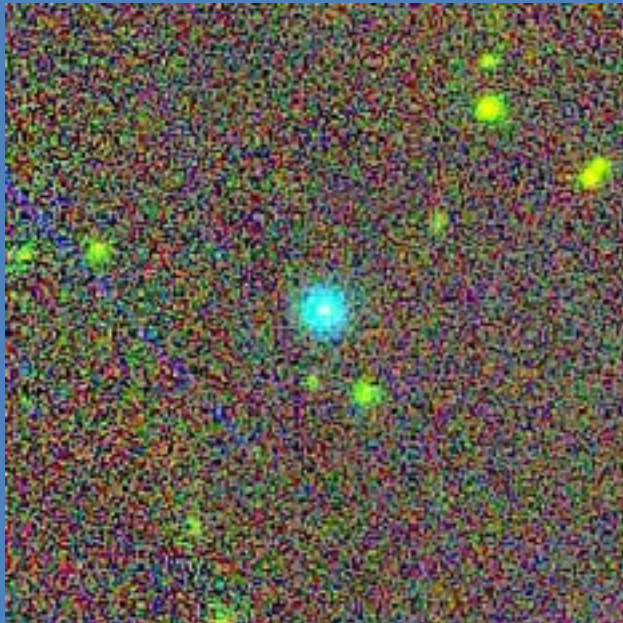
### Observation with Keck

John Debes told us this white dwarf is cold, in fact it was 1000 Kelvin cooler than any known white dwarf with an infrared excess. So the researchers decided to observe it with APO. But the dome was closed because of bad weather. Soon the white dwarf was observed with Keck! The telescope with the largest mirror on this planet!

I watched closely how things developed. I made a timeline (*see right*).

Date	
2018-10-17	Discovery of LSPM J0207+3331 (still no clue what it could be)
2018-10-19	Sending LSPM J0207+3331 to the researchers
2018-10-20	Bad weather at APO
2018-10-27	LSPM J0207+3331 is being observed with Keck (Adam Burgasser observed it for us – THANK YOU!!)
2018-12-01	Paper is submitted to ApJ Letters
2019-02-02	Paper is accepted

Melina Thévenot, 's timeline of her discovery, the subsequent Keck 8-metre telescope confirmation, and eventual publication of her discovery in the on Feb 19, 2019 issue of the *Astrophysical Journal*



The blue object in the centre is a T-dwarf that lies at a distance of 44 parsec; this is beyond Gaia's detection radius at this distance.

### A 3 Gyr White Dwarf with Warm Dust

Let's talk about the paper. Des Pudels Kern. (German Saying, "The core of the poodle" meaning the main point).

What is a white dwarf? Our sun will develop into a red giant billion of years in the future. The red giant will lose the outer layers in a Planetary Nebula. The core that is left is a hot white dwarf and it will gradually cool and become fainter.

The process is very violent and "loosing the outer layers" is nothing else than burning the orbiting planets in strong solar winds. But not everything will perish. White dwarfs have a leftover stellar system with asteroids, comets and planets. If an asteroid or comet comes too close to the white dwarf, it can be torn apart by the tidal forces caused by the gravity of the white dwarf and the material settles down in a disk around the white dwarf.



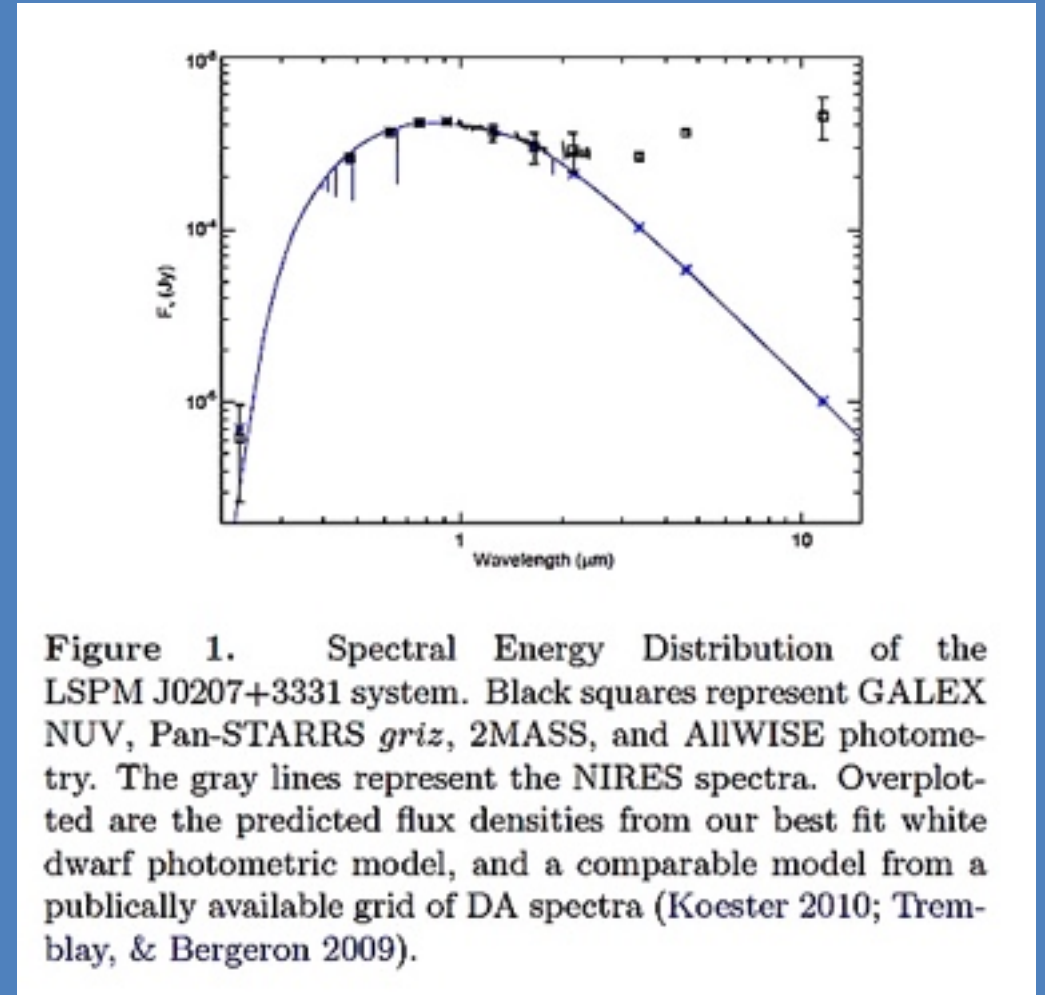
In figure 1 of the paper you can see a blue line. This is how the Spectral Energy Distribution (SED) of the white dwarf should look like without a disk. The gray lines are the spectra from Keck NIRES and the black squares are the photometry from different surveys. You can see how the spectra and the photometry are somehow taking off to the right side. This blog post from Disk Detective explains what a SED is and how a SED looks like for star +disk. It might help you interpret this figure.

Models that try to describe disks around white dwarfs predict that young white dwarfs are more likely to develop a disk. It is therefore surprising that a 3 Gigayear (3 Billion years old) white dwarf has a disk. Is LSPM J0207+3331 special or are the models about the formation of disks around white dwarfs not accurate enough? Future searches for similar white dwarfs might shine light on this mystery.

But this is not where the story of this white dwarf ends. The disk around LSPM J0207+3331 is not a simple disk, but it consists of two components: an outer colder ring with a temperature of 480 Kelvin and an inner ring with a temperature between 550-1400 Kelvin. The white dwarf has an temperature of 6120 Kelvin and a mass of 0.69 solar masses. The outer ring might have formed from a small asteroid that was disrupted by the tidal forces in the recent history of the system. This is the first time such a system was observed.

In the future, researchers will observe this white dwarf again and obtain more data, which might tell more about this system. An optical spectrum, for example, might tell us if any material from the disk is falling into the atmosphere of the white dwarf, and what that material is made of.

I am very proud to be part of this discovery and hope you enjoyed reading this blog post.



# How well does your kid's school teach astronomy?

## The world of astronomy applets and simulations

Visualising the intricacies of astronomy equations is difficult for those who do not know what the real-life behaviour of planets, stars, and galaxies is supposed to look like. Since astronomy is not exactly a hasty science, the slow evolution of gradual change in the sky can best be understood if it is speeded up to match our everyday TV, movie, and cellphone experience.

Fortunately for parents and teachers alike, the hard work of creating computer simulations that realistically — and often beautifully — re-create events in the sky has been a long-term goal of numerous organisations around the world.

Today's astronomy-education teacher aids have become so sophisticated that it is easiest for a teacher to show a simulation to their learners before introducing the verbal descriptions and maths. Since astronomy education such a big world, we start with the basics — lesson plans, classroom activities, and the vast body of Applets and simulations.

Listed on the pages below is a get-acquainted sampler of the astonishing variety of educational materials available by simply clicking on a link.

ASSA regional clubs and members can use this list to produce their own club astronomy seminars and classes. Or, interested ASSA members can meet with the principals of their schools to introduce teachers and administrators to the excellent body of course and lecture materials available absolutely free.

# Astronomy Resources for the EL-Hi School Classroom

*[The Physics Front](#) teaching aids have all you need to teach astronomy to anyone.*

## Lesson Plans:

### [Interactive Classroom Materials for Introductory Astronomy](#)

Impressive set of modules on astronomy appropriate for the advanced high school level. Interactive web-based concept questions promote active group discussion. Each topic is accompanied by animations and/or simulations. This is a work in progress at the University of Nebraska-Lincoln.

*Level: Grades 9-12*

### [Imagine the Universe! Lesson Plans](#)

Ten standards-aligned lesson plans developed for grades 7-12 on space science and the evolution of the universe. Topics include the electromagnetic spectrum, satellite image data analysis, the origin of the elements, supernovae, and gamma-ray bursts. Look for the printable student guides.

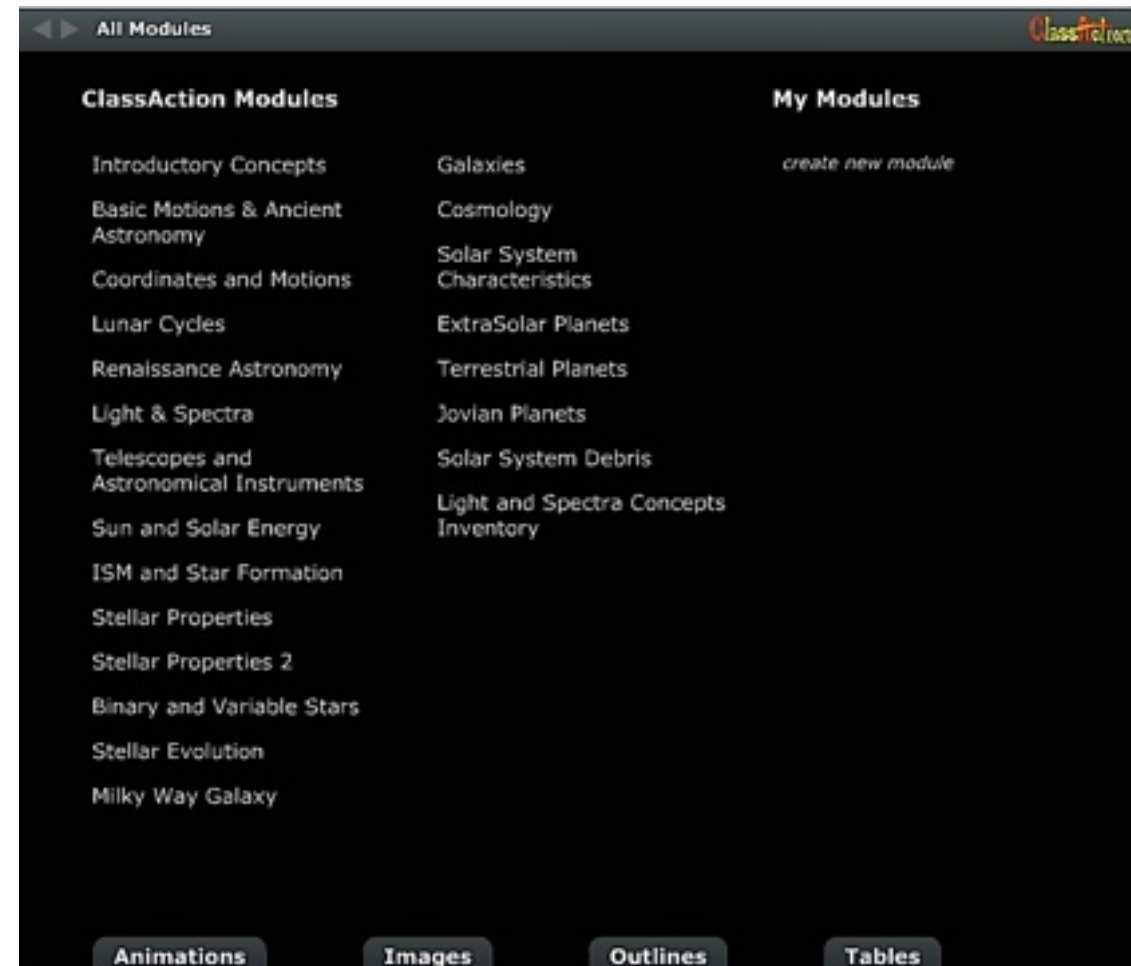
*Level: Grades 9-12*

### [Orbital Motion](#)

In this activity students will explore orbital shapes and properties.

### [ASPIRE Star Life Cycle](#)

A terrific interactive tutorial on the evolution of stars. It integrates activities, graphs, quizzes, and animations to trace a star's life from protostar stage through "old age" and death.



Each of these [Univ. of Nebraska \(USA\) Class Activity Modules](#) leads to a series of web pages with lessons, applets, and reference links to other websites. While notable in their own right, the Univ. of Nebraska is just one of many similar web sites for educators that are presented in the following pages.

[Nebraska Astronomy Applet Project: Solar System Models Lab](#) [see right]

Explore both the Ptolemaic (geocentric) and Copernican (heliocentric) models of the solar system in this module that features two simulations, comprehensive student guide, pre-test, post-test, and content support for teachers. *Level: Grades 9-12*

[Nebraska Astronomy Applet Project: Basic Coordinates and Seasons Lab](#)

In this module, you'll find simulations for introducing terrestrial coordinates (latitude/longitude), celestial equatorial coordinates, and how Earth's seasons are related to its axial tilt. It will help build a foundation for understanding obliquity, the angle between an object's rotational axis and a line perpendicular to its orbital plane. Knowledge of obliquity is crucial for astronomy calculations and Earth-based observation. Includes detailed student guide, assessment materials, and background information.

*Level: Grades 9-12.*

[NASA Jet Propulsion Lab: Eyes on the Solar System](#)

Here you'll find a rich array of visualisation tools for a 3D exploration of our cosmic neighbourhood. The website uses actual data and images generated from past and present space missions. Students can zoom, change lighting, "ride-on-board", do scale comparisons, and replay events in real or accelerated time. Adaptable for a range of grade bands and ability levels.

*Level: Grades 9-12.*

[Welcome to the Planets](#)

A set of images of all the planets with accompanying video, statistics, and NASA exploration information.

*Level: Middle school and high school.*

The screenshot shows the 'Ptolemaic System Simulator' interface. At the top, a navigation bar contains links for Home, ClassAction, NAAP Labs, Interactives, Video, Mobile, Downloads, Local, More, and Contact. Below this, a breadcrumb trail reads 'Home > NAAP Labs > Solar System Models > Ptolemaic System Simulator'. The main simulation area is titled 'Ptolemaic System Simulator' and includes 'reset', 'help', and 'about' buttons. The 'Orbit View' displays the Earth at the center with two overlapping orbits: a larger equant circle and a smaller epicycle. The planet Mars is shown on the epicycle. Zodiac signs are labeled around the perimeter: Cancer, Gemini, Taurus, Aries, Pisces, Aquarius, Capricorn, Sagittarius, Scorpius, Libra, Virgo, and Leo. A 'Memory' section has 'store' and 'recall' buttons. To the right, the 'Planetary Parameters' section for Mars includes a 'presets' dropdown (set to Mars), an 'OK' button, and sliders for 'epicycle size' (0.66), 'eccentricity' (0.10), 'motion rate' (0.52), and 'apogee angle' (106.7). A 'planet type' section has radio buttons for 'superior' (selected) and 'inferior'. Below this, the 'Controls and Settings' section has a 'start animation' button, an 'animation rate' slider, and checkboxes for 'show deferent', 'show planet vector', 'show epicycle', 'show equant vector', 'show earth-sun line', and 'show epicycle-planet line'. A 'path duration' slider is also present. At the bottom, the 'Zodiac Strip' shows icons for each zodiac sign, and the 'Key' section explains that the Earth is stationary at the center.

This [University of Nebraska applet of the Ptolemaic System](#) is just one example of the Astronomy Education Department's remarkable array of easy-to-learn applets and simulations for students of all ages. Their website is worth an extended try-it-yourself visit. Best of all, every simple sim is f-r-e-e. (Where were these folks when WE were learning all this with chalk on blackboards??)

## [Spectra](#)

Easy-to-navigate reference material that explains how astronomers use spectra to understand star composition, structure, and evolution. Contains multiple drawings and photos.

## [NASA: Solar System Exploration](#)

Beautifully organised website offers a wealth of information about the objects in our solar system, recent technology used to explore these worlds, space missions, and stories about the people behind the missions. Browse image galleries, explore multimedia resources, find lesson plans, or download videos and animations. Look under the sections on "Missions" and "Technology" for materials designed for high school learners.

*Level: Grades 9–12.*

## [Black Holes - An Introductory Resource List](#)

A well-constructed guide to non-technical books, articles, and web sites about black holes. Don't miss the sections on the large black hole at the centre of the Milky Way and links to animations that model the black hole phenomenon.

*Level: Grades 8–12.*

## **Content Support For Teachers:**

### [Kepler and His Laws](#) (see sample image right)

This set of materials pertaining to Kepler's laws includes equations and properties of conic sections, scale of the solar system, the energy equation for Keplerian motion, and Newton's "Universal Gravitation". It is part of a larger collection that offers lesson plans, lecture materials, and historical background.

## **Student Tutorials:**

### [Interactive Classroom Materials for Introductory Astronomy](#)

Impressive set of modules on astronomy appropriate for the advanced high school level. Interactive web-based concept questions promote active group discussion. Each topic is accompanied by animations and /or simulations.

Right: This sample page from the section on Johannes Kepler is part of the overall web section "[From Stargazers to Starships](#)" by David Stern on the [psys6.org](#) educational materials website.

## **Ellipses!**

The ellipse, the shape of a flattened circle, was well known to the ancient Greeks. It belonged to the family of "conic sections," of curves produced by the intersections of a plane and a cone.

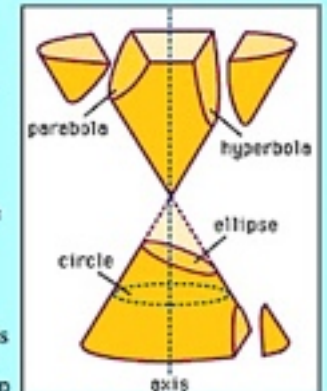
As the drawing above on the left shows, when that plane is...

- perpendicular to the axis of the cone, the result is a **circle**.
- moderately inclined, an **ellipse**.
- inclined so much that it is parallel to one side of the cone, a **parabola**.
- inclined even more, a **hyperbola**.

(and when the plane includes the tip of the cone, it becomes two intersecting straight lines. That is the shape of a hyperbola under extreme magnification, when its curving tip becomes insignificantly small.)

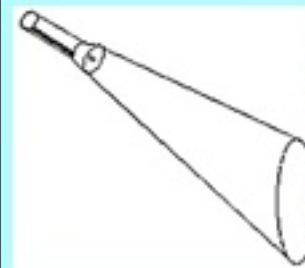
All these intersections are easily produced by a flashlight in a moderately dark room (drawing below). The flashlight creates a cone of light and when that cone hits a wall, the shape produced is a conic section--the intersection of the cone of light with the flat wall.

The axis of the flashlight is also the axis of the cone of light. Aim the beam perpendicular to the wall to get a **circle** of light. Slant the beam: an **ellipse**. Slant further, to where the closing point of the ellipse is very, very far: a **parabola**. Slant even more, to where the two edges of the patch of light not only fail to meet again, but seem to head in completely different directions: a **hyperbola**.



The curves generated as "conic sections" when flat planes are cut across a cone.

## **The Third Law**




After Tycho's death, Kepler became the court astronomer, although the superstitious emperor was more interested in astrology than in the structure of the solar system. In 1619 Kepler published his **third law**: the **square of the orbital period  $T$**  is proportional to the **cube of the mean distance  $a$**  from the Sun (half the sum of greatest and smallest distances). In formula form

$$T^2 = k a^3$$


with  $k$  some constant number, the same for all planets. Suppose we measure orbital periods in years and all distances in "astronomical units" or AUs, with 1 AU the mean distance between the Earth and the Sun. Then if  $a = 1$  AU,  $T$  is one year, and  $k$  with these units just equals 1, i.e.  $T^2 = a^3$ . Applying now the formula to any other planet, if  $T$  is known from the observations of many years, the planet's  $a$ , its mean distance from the Sun, is readily derived.

JPL HOME EARTH SOLAR SYSTEM STARS & GALAXIES TECHNOLOGY



# Basics of Radio Astronomy

Jet Propulsion Laboratory  
California Institute of Technology





This workbook, although applicable to all radio astronomy, was developed to support training for the Goldstone-Apple Valley Radio Telescope.

What is the Goldstone-Apple Valley Radio Telescope?

What's the purpose of this "workbook"?

[Download Basics of Radio Astronomy \(.pdf\)](#)


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Published by  
Jet Propulsion Laboratory  
Mission Execution and Automation Section  
Customer Integration Services Group

Document No. JPL D-13835

### [Basics of Radio Astronomy](#) [see splash page left]

This tutorial, sponsored by NASA's Jet Propulsion Laboratory, is a cost free online workbook/tutorial on the fundamentals of radio astronomy. It would be appropriate to augment a unit on electromagnetic radiation, and includes a unit exam. Available as a downloadable PDF.

### [Field-Tested Learning Assessment Guide](#)

This is an assessment guide for STEM instructors. Learn about research-based assessment design and view examples of varied classroom assessment techniques (CAT's). Diagnostic pre-tests are included for both astronomy and physics learners.

### [Mass - Comparing Masses Without Use of Gravity](#)

How to measure mass in a weightless environment

This Nebraska Astronomy Applet module introduces the search for planets outside of our solar system using the radial velocity and transit methods. Planets around other stars proved very elusive to find until 1995, when astronomers in Geneva detected an exoplanet using the radial velocity (or Doppler) technique. Since that time, hundreds of exoplanets have been discovered in this manner. The transit method, used in the Kepler Mission is explained in this module. *Level: Grades 9-12*

## **Activities:**

### [StarDate Classroom Activities](#)

A collection of standards-based lesson plans for K-12 developed to help teachers integrate astronomy into the physical science classroom.

*Level: Grades K-12*

### [Amazing Space](#)

All about space and the objects in it.

### [Double Vision: How we learned the distance to the stars](#)

Using the parallax method to calculate astronomical distances.

[Folding Paper Model of the Magnetosphere](#) [see DIY image right]

This website provides instructions and an image which can be downloaded, printed on a regular page, copied by a xerox machine (preferably, onto stiff paper), cut and folded to produce [a model of the Earth's magnetosphere](#). A supplement to "Exploration of the Earth's Magnetosphere" whose index page is linked at the beginning and the end of the above page. [See this page for simple step-by-step instructions.](#)

[Astronomy and Physics Simulations from www.astronomycenter.org](#)

This collection of animations and simulations illustrate galaxy collisions, fusion in the sun, the Big Bang, the inverse square law, searching for black holes, the H-R diagram, eclipsing binary stars, proper motion, parallax, the Doppler Effect, blackbody radiation, and Solar System exploration. *Level: Grades 11–12 & undergrad.*

The University of St. Andrews in Scotland has produced an exceptionally comprehensive [Guide for Astronomical Learning and Teaching Resources](#) database covering class lecture plans, websites, and software/app resources for teachers from *K–12 to varsity*.

[Concordia University in Oregon, USA](#) offers a list of weblinks to databases, books, and reference materials for the study of physics and astronomy in [Physics & Astronomy: Physics Simulations](#). Each of the many icons can be copied as an image for reproduction on paper, or linked through to full-motion applets for emailed or online lesson plans. You can have fun for hours playing with the 49 clickable applets, even if they are targeted for *K–12 teachers*.

**When you've tried all these and everything else, too, go to [Physics Applets to Demonstrate Astronomy](#) and see what you missed.**

## Astronomy applets and simulations

Visualising the intricacies of astronomy equations is difficult for many people, not least of which are young students unfamiliar with what the real-life behaviours of planets, stars, and galaxies is supposed to look like. Fortunately for parents and teachers, the hard work of creating computer simulations has been an ongoing effort by numerous organisations around the world. The sims have become so sophisticated that it is easier to run a simulation to a student or class before translating backwards into the maths and verbal descriptions.

### University of Colorado PhET simulations

[PhET Interactive Simulations](#) are an amazing assemblage of over 100 applets and sims depicting motion, sound and waves behaviour, work-energy-power, heat & thermodynamics, quantum phenomenon, light & radiation, and electrical circuits & magnetism. Let your kids loose on this and there will be peace and quiet in the house for hours.

[A Physics Applet to demonstrate: Kepler's Second Law](#)

The world of [applets designed to visually depict astronomical properties](#) is a very large one. These Java applets model the motion of planets using Kepler's Second Law. The time taken to sweep out equal areas on opposite sides of the orbit is shown. The semi-major axis and eccentricity of the orbit can be changed. There is also an option to show the velocity vector of the orbiting object. This is available in a different language and is part of a large collection of similar physics applets.

# Star Life Cycle

Although stars may seem like permanent fixtures in the sky, they are actually very dynamic objects. Stars grow old and die, while new stars are being formed all throughout the universe.

This lesson is designed to help you learn about this process. It will discuss where stars come from, how they form, what keeps them going and what happens to them after they die. It will also show how the birth and death of stars is responsible for creating most of the elements that make up the earth and the rest of the universe.

The lesson is divided up into five sections, each one discussing a particular topic in astrophysics or a specific period in a star's life cycle.

 <b>Studying Stars</b>	Learn about how astronomers study the stars and how things like light and color allow them to understand the way stars develop.
 <b>Protostars</b>	Find out where stars come from and what factors determine the kind of star they turn into.
 <b>Main Sequence</b>	Learn more about the longest phase of a star's life and about the reactions that keep stars burning for millions of years.
 <b>Old Stars</b>	Find out about all the different things that can happen to a star as it begins to grow old.
 <b>Stellar Remnants</b>	Discover what happens to a star after it dies. Many of the most mysterious objects in the universe are not true stars, but the remains of stars that have long since died.



In addition to the main lesson, further information and definitions of key terms can be found in the appendix section.

Appendix

- Glossary
- Advanced Fusion
- Image Terms of Use

### [StarChild: A Learning Center for Young Astronomers](#)

StarChild is an online astronomy learning centre for elementary and middle school students. Included are materials about the solar system, the Milky Way galaxy, and extra-galactic astronomy. Materials are divided into two different grade levels: K-8 and high school physical science.

### [Where Is Polaris?](#)

The University of Chicago Digital Library Development Centre teamed with the Adler Planetarium & Astronomy Museum to produce this interactive tutorial that shows why Earth's rotation makes it appear that stars are orbiting the Earth. The simulation features Polaris (the North Star) as its focal point to show that stars are fixed in their positions -- it's the Earth which is moving as it rotates on its axis, offering hour-by-hour views of the sky on a clear night from both reference points.

### [Nebraska Astronomy Applet Project: Extrasolar Planets Lab](#)

The NAAP Extrasolar Planets Lab introduces the search for planets outside of our solar system using the Doppler and transit methods. It includes simulations of the observed radial velocities of singular planetary systems and introduces the concept of noise and detection. The two applets on the website, the [Exoplanet Radial Velocity Simulator](#) [swf] and [Exoplanet Transit Simulator](#) [swf] explain centre of mass, Doppler shifting, object detection, and object simulation. Both simulations require Adobe Flash.

### [Online educational resources for Physics teachers](#)

This is an extensive list of web-based resources for teaching physics and math. Its target student levels are upper high-school and undergraduate. Many links are to collections of resources, many simulations or animations of concepts. [Reference material is also included.](#) (A few of the links are no longer active.)

Left: [ASPIRE: Star Life Cycle](#) © University of Utah, USA.



## Astronomy education material for K-12 (pre-school to honours level)

[ASPIRE \(Astrophysics Science Project Integrating Research and Education\) lesson plans](#) [see image to right]

This comprehensive web site of lessons, tutorials, and teacher assessment tools includes free access to interactive science labs with downloadable simulations. Half of the simulations are related to Astronomy and half pertain to general topics such as simple machines, force, motion, momentum, and kinetic energy. Each interactive lab is designed to be visually attractive and fun, yet mentally challenging for students in the middle grades. Materials include complete lesson plans which were authored collaboratively by teachers and research scientists. (Requires Adobe Flash.) **Level: Grades 4–9.**

### Activities:

[Kepler: A Search for Habitable Planets.](#)

NASA's Kepler Mission was launched in 2009 with the focused goal of surveying regions of the Milky Way Galaxy to discover Earth-size planets. The spacecraft's detection instrument is a photometer that continually monitors 145,000 stars to locate exoplanets in the "habitable zone" of a star, where liquid water and possibly life might exist. The website tracks information about mission results, with more than 2,000 candidates identified after the first year's operation. Of those, two Earth-size candidates have been confirmed as of January, 2012. Educators will also find classroom activities, interactive resources, simple animations showing how the detection system works, and galleries of photos, videos and 3D images.

[Ed. note: The Kepler Mission employed the Transit Method of exoplanet detection. [See here for an animation that will help students understand the Transit Method.](#)]

Right: [ASPIRE Lesson Plans](#) (most include applets or sims) & some require Flash.

LESSONS	
 <b>Bread Board</b> <i>A project teaching basic electronics, programming and concepts about persistence of vision.</i>	 <b>Cosmic Zoom</b> <i>Zoom in from the far reaches of the galaxy by powers of ten.</i>
 <b>Force and Motion</b> <i>Learn about the effect of force on velocity and motion.</i>	 <b>Gas Particles in Motion</b> <i>Learn about the relationships between volume, temperature, and pressure.</i>
 <b>In Search of Cosmic Rays</b> <i>Learn about how scientists search for Cosmic Rays.</i>	 <b>Kinetic Energy</b> <i>Learn about the relationships between mass, speed, and energy.</i>
 <b>Lunar Phases</b> <i>Learn about the lunar phases.</i>	 <b>Machines</b> <i>Learn about simple and complex machines!</i>
 <b>Night Sky Viewer</b> <i>See the night sky anywhere on Earth!</i>	 <b>Our Atmosphere</b> <i>Learn about the atmosphere.</i>
 <b>Refraction Demos</b> <i>Learn about how light refracts through prisms and raindrops.</i>	 <b>Scientific Method</b> <i>The scientific method and its application to astronomy.</i>
 <b>Scientific Notation</b> <i>Learning to use large numbers.</i>	 <b>Seasons Activity</b> <i>Use a sundial to observe seasonal changes.</i>
 <b>Seasons Exercise</b> <i>Use seasons to determine your location.</i>	 <b>Seismic Waves</b> <i>How do scientists know what the core of the Earth looks like? Learn more about seismic waves and find out.</i>
 <b>Shoot the Stars</b> <i>Use the Doppler effect in this virtual lab to learn if a star is moving toward or away from Earth.</i>	 <b>Star Life Cycle</b> <i>Learn the full life cycle of a star.</i>
 <b>Sun Angle</b> <i>Why doesn't it get warm at the North Pole like it does at the equator, even though it has 24-hour days?</i>	 <b>Tides</b> <i>Learn about the Earth's tides.</i>

# IMAGINE THE UNIVERSE!

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 Science  
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 Big Questions  
 Featured Science  
 Observatories  
 Special Exhibits  
 Educators' Corner  
 Ask an Astrophysicist  
 Resources  
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Additional Links  
 Quiz me about this topic!  
 Cool fact about this topic!  
 Try this!  
 Give me additional resources!

For Educators  
 NCTM & NSES Standards  
 Show me related lesson plans

**Astronomer's Toolbox** Search

Basic Advanced

## The Electromagnetic Spectrum

The electromagnetic (EM) spectrum is the range of all types of EM radiation. Radiation is energy that travels and spreads out as it goes – the visible light that comes from a lamp in your house and the radio waves that come from a radio station are two types of electromagnetic radiation. The other types of EM radiation that make up the electromagnetic spectrum are microwaves, infrared light, ultraviolet light, X-rays and gamma-rays.

You know more about the electromagnetic spectrum than you may think. The image below shows where you might encounter each portion of the EM spectrum in your day-to-day life.

Radio	AM radio	Radio: Your radio captures radio waves emitted by radio stations, bringing your favorite tunes. Radio waves are also emitted by stars and gases in space.
	Analog radio	
Microwave	Aircraft communication	Microwave: Microwave radiation will cook your popcorn in just a few minutes, but is also used by astronomers to learn about the structure of nearby galaxies.
	Microwave oven	
Infrared	TV Remote Control	Infrared: Night vision goggles pick up the infrared light emitted by our skin and objects with heat. In space, infrared light helps us map the dust between stars.
	Night vision goggles	
Visible	Visible light	Visible: Our eyes detect visible light. Fireflies, light bulbs, and stars all emit visible light.
Ultraviolet	UV light from the Sun	Ultraviolet: Ultraviolet radiation is emitted by the Sun and are the reason skin tans and burns. "Hot" objects in space emit UV radiation as well.
X-ray	Airport security scanner	X-ray: A dentist uses X-rays to image your teeth, and airport security uses them to see through your bag. Hot gases in the Universe also emit X-rays.
	PET scan	
Gamma-ray	Terrestrial gamma-ray flashes	Gamma ray: Doctors use gamma-ray imaging to see inside your body. The biggest gamma-ray generator of all is the Universe.

The electromagnetic spectrum from lowest energy/longest wavelength (at the top) to highest energy/shortest wavelength (at the bottom). (Credit: NASA's Imagine the Universe)

### [Exoplanet Exploration: Planets Beyond Our Solar System](#)

This website is dedicated to keeping the public updated and informed about the recent discoveries of exoplanets. This website provides information on NASA's missions, the technology used to detect exoplanets, the history of discovering exoplanets, how planets and solar systems form, and the people and projects involved in discovering other planets. There are activities, animations, and a photo gallery for educators. **Level: High school to undergraduate.**

### [NASA Jet Propulsion Lab: Eyes on the Solar System](#)

Here you'll find a rich array of visualisation tools for a 3D exploration of our cosmic neighbourhood. The website uses actual data and images generated from past and present space missions. Students can zoom, change lighting, "ride-on-board", do scale comparisons, and replay events in real or accelerated time. **Adaptable for a broad range of grade bands and ability level, generally grades 3–12.**

### [NASA: JPL Solar System Simulator](#)

See virtual images of each planet and its moons as seen from Earth, the Sun, or from any other planet in the solar system. Time parameters may be set from 1990-2025 to enable virtual viewing at certain dates. **Level: Grades 7–12.**

### [NASA: Solar System Exploration](#)

NASA's Solar System Exploration website offers a wealth of information about the objects in our solar system, recent technology used to explore these worlds, space missions, and stories about the people behind the missions. Users will find image galleries, multimedia resources for teachers and learners, videos, animations, and other interactive features to explore the planets, comets, asteroids, the history of robotic exploration, and future missions. **Level: K–12.**

### [Imagine the Universe](#) (see sample page left)

This comprehensive NASA website, intended for adolescent learners, provides timely news and information about space exploration and space science. Included are many creative resources, such as "[Ask an Astrophysicist](#)", "[What does the astrophysicist do?](#)", "[Satellite Showcase](#)", and [High-Energy X-ray and gamma ray observatories](#).



**Editor selections by Topic and Unit**

- **K-8 Phys. Science**
- **Physics First**
- **Conceptual Physics**
- **Algebra-based**
- **AP-Calculus**

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**Education Foundations**

[Achievement](#), [Alternative Conceptions](#), [Assessment](#), [Behavior](#), [Cognition](#), [Communication](#), [Learning Theory](#), [Problem Solving](#), [Research Design & Methodology](#), [Sample Population](#), [Societal Issues](#), [Student Characteristics](#), [Teacher Characteristics](#)

**Electricity & Magnetism**

[General](#), [Electrostatics](#), [Electric Fields and Potential](#), [Capacitance](#), [Resistance](#), [Electromotive Force and Current](#), [DC Circuits](#), [Magnetic Materials](#), [Magnetic Fields and Forces](#), [Inductance](#), [Electromagnetic Induction](#), [AC Circuits](#), [Semiconductors and Tubes](#), [Electromagnetic Radiation](#)

**General Physics**

[Collections](#), [Computational Physics](#), [Curriculum](#), [Equipment](#), [General](#), [History](#), [Measurements/Units](#), [Philosophy](#), [Physics Education Research](#), [Properties of Matter](#), [Scientific Reasoning](#)

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[Acoustics](#), [General](#), [Instruments](#), [Oscillations](#), [Resonance](#), [Sound](#), [Reproduction](#), [Wave Motion](#)

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[General](#), [Foundations and Measurements](#), [Probability](#), [Waves](#), and [Interference](#), [Bound State Systems](#), [Scattering and Unbound Systems](#), [Quantization](#), [Multi-particle Systems](#), [Approximation Techniques](#), [Entanglement and Quantum Information](#), [Quantum Experiments](#)

**Thermo & Stat Mech**

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**Classical Mechanics**

[General](#), [Motion in One Dimension](#), [Motion in Two Dimensions](#), [Relative Motion](#), [Newton's First Law](#), [Newton's Second Law](#), [Newton's Third Law](#), [Statics of Rigid Bodies](#), [Applications of Newton's Laws](#), [Gravity](#), [Work and Energy](#), [Linear Momentum](#), [Rotational Dynamics](#)

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[Active Learning](#), [Careers](#), [Classroom Management](#), [Curriculum Development](#), [Informal Education](#), [Instructional Material Design](#), [Learning Environment](#), [Pedagogy](#), [Professional Development](#), [School Improvement](#), [Teacher Preparation](#), [Technology](#)

**Fluid Mechanics**

[Dynamics of Fluids](#), [General](#), [Statics of Fluids](#), [Surface Tension](#)

**Mathematical Tools**

[Algebra](#), [Trig and Pre-cal](#), [Vector Algebra](#), [Calculus](#), [Complex Variables](#), [Coordinate Systems](#), [Differential Equations](#), [Linear Algebra and Tensors](#), [Series and Functions](#), [Probability](#), [Statistics](#)

**Optics**

[Color](#), [Diffraction](#), [General](#), [Geometrical Optics](#), [Interference](#), [Modern Optics](#), [Photometry](#), [Polarization](#), [The Eye](#)

**Other Sciences**

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**Relativity**

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Carina Nebula by [Tanja Schmitz](#) on [Karoo Nights](#).

# The First Moon Map: Hevelius's Selenographia, 1687



Johannes Hevelius,  
Selenographia, 1687.  
By courtesy of Barry  
Lawrence Ruderman,  
antiquarian maps.

# Ordering the Heavens: Johannes Hevelius's Revolutionary 17th-Century Star Catalog and the First Moon Map

Maria Popova, reprinted from [brainpickings.org](http://brainpickings.org)

On September 26, 1679, a fierce fire consumed the *Stellaburgum* — Europe's finest observatory, built by the pioneering astronomer **Johannes Hevelius** (January 28, 1611–January 28, 1687) in the city of Danzig, present-day Poland, decades before the famous Royal Greenwich Observatory and Paris Observatory existed.

That autumn day, Hevelius — whose exquisite lunar engravings are considered the first true maps of the moon and who believed, long before it was established by scientific consensus, that the stars in the night sky were thousands of suns like our own — had retired to a garden outside the city, “feeling himself oppressed with great and unaccustomed troubles, as if presaging some disaster,” as a friend later recounted in a letter.

In Hevelius's absence, his coachman had left a burning candle in the stable and the wooden platform across the roofs of Hevelius's three adjoining houses, upon which his fine brass instruments and telescopes were mounted, had caught aflame. As the fire raged on, the town's people broke into the observatory trying to save Hevelius's precious bound books, throwing them out the windows. Some survived, some were pilfered. His optical instruments and almost all of his bountiful unbound manuscripts perished.

**Johannes Hevelius, at the age of 68 when this portrait was engraved, had spent his life drawing the first maps of the moon, praised for their detail, from his homemade rooftop observatory in the Kingdom of Poland.**

Hevelius was sixty-eight when his observatory was destroyed. But despite having spent forty years building his own instruments, making groundbreaking observations with them, and engraving and printing his own books — fruits of labor most of which were consumed by the fire along with all his “worldly Goods and Hopes,” as he later wrote in a letter to the king of France — he refused to sink into bitterness and resignation. Instead, he set out to rebuild the observatory so he could return to observing the stars.

His resilience was in large part fuelled by the miraculous salvation of one of his manuscripts — his fixed-star catalog, which contained the results of thousands of calculations of the positions of the stars made over decades of patient observation. The small leather-bound notebook was the sole manuscript to survive the fire, presumably saved by Hevelius's 13-year-old daughter Katharina Elisabeth, the sole family member in Danzig at the time of the fire, who had a key to her father's study.

Half a millennium later, it was rediscovered. In 1971, it made its way to Utah's Brigham Young University, becoming the one-millionth acquisition by the institution's library. To mark the landmark event, the university published a slim volume titled *Johannes Hevelius and His Catalog of Stars* (public library) — an immeasurably engrossing chronicle of the life and legacy of Hevelius, the 300-year odyssey of his fixed-star catalog, and how it changed our world.



Hevelius was born in 1611, a year after Galileo had made his first observations with a telescope, at a time of blazing scientific breakthrough and controversy. His father, a successful merchant, pressed young Johannes to follow in his footsteps rather than pursue what he perceived to be the fool's gold of the scientific revolution, and sent the nine-year-old boy to Poland to study Polish. At the time, Danzig was part of the Prussian Confederation and Hevelius's native language was German, something his father saw as an obstacle to doing trade. When the boy returned at age sixteen, he pleaded with his father to allow him to continue his formal education. The old man eventually relented and young Hevelius quickly fell in love with mathematics, under the influence of his mentor, the acclaimed mathematician, astronomer, and polymath Peter Krüger. He also learned Latin, the language of most scientific publications and international correspondence, and under Krüger's nurturing watch began learning to draw, engrave, and build rudimentary instruments out of wood and metal. As Krüger's sight began deteriorating, he encouraged young Johannes to take an active part in the observation part of science.

When he was nineteen, Hevelius watched the total solar eclipse of 1630 and saw Saturn veil the moon in a rare lunar eclipse. He was filled with cosmic awe, but wasn't ready, or didn't yet know how, to translate this sense of purpose into a career in astronomy. Instead, he married the daughter of a distinguished businessman and settled into the comfortable life of a merchant. But in 1639, when Krüger was on his deathbed, he urged young Hevelius not to let his exceptional gift go to waste. Aware that his end was near, Krüger lamented that he would miss the rare solar eclipse about to occur later that year and exhorted Hevelius to take up the historic task of its observation.



Johannes Hevelius's autograph, photocopied from a document signed about the same period as the publication of his *Selenographia* in 1687.



The manuscript of 'Catalogus Stellarum Fixarum,' Johannes Hevelius's fixed-star catalog still shows char marks on the edges of the pages. Scholars who have examined it say that it still smells faintly of paper scorch.



Equipment used by Hevelius with a telescope to project an astronomical image onto a sheet of paper. This arrangement was used in his historic observation of the transit of Mercury on May 3, 1661.

His teacher's dying words reawakened Hevelius's forsaken but fiery love of astronomy. On June 1, 1639, he meticulously observed the solar eclipse, then decided to dedicate the rest of his life to understanding the cosmos. True to the notion that revolutionary discovery is the product of "the meeting of the right people at the right place with just the right problem," Hevelius harnessed the fruitfulness of his timing — just as he chose to devote himself to astronomy, the telescope was revolutionizing the field and making possible discoveries never before imagined.

Hevelius was particularly enchanted with the moon and made it the target of his first obsessive observations. Dissatisfied with the imprecise and vague drawings of its surface, he decided to complain the way all innovators do — by making something better. Turning his modest telescope to the moon and enlisting his talents as a draftsman and engraver, he set out to create a large, complete, delicately detailed map of its surface. But he quickly realised his telescope wasn't up to the task — so he decided to build a better one himself. In 1647, after five years of methodical work fuelled by this greatest talent — dogged patience — Hevelius published his magnificent maps under the title *Selenographia*.

One of his first great admirers was the famed English traveler Mundy who, upon seeing the maps, marvelled in his diary:

*Of the Moone he hath Made above 30 large mappes, prints, or Copper peeces of the Manner of every daies encrease and decrease, deciphering in her land and sea, Mountaines, valleies, Ilands, lakes, etts., making in another little world, giving Names to every part, as wee in a mappe of our world.*

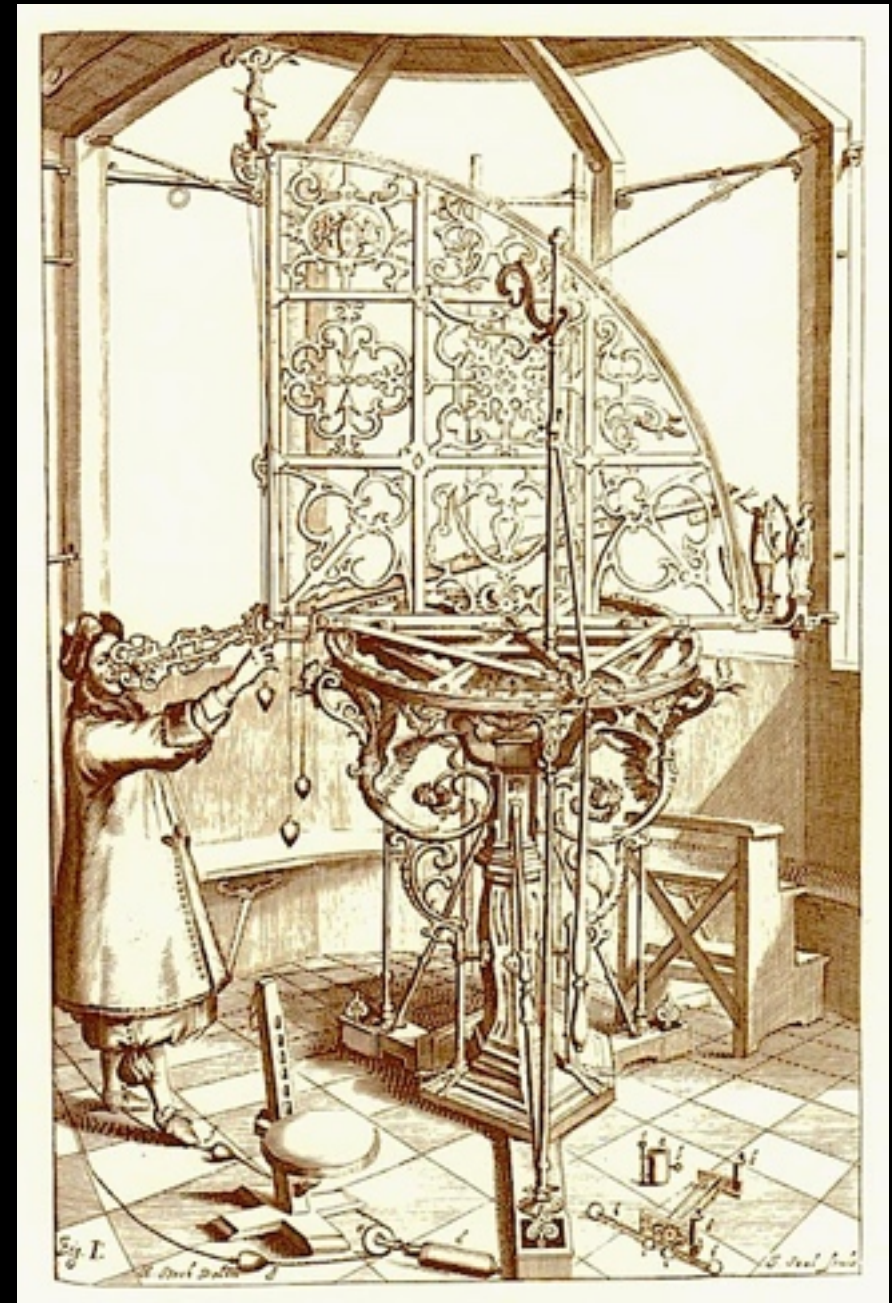
Praise continued to pour in from all over Europe, but the greatest validation of the maps' merit was the fact that they endured as the best moon maps for more than a century, despite the rapid progress of observational tools — assurance, perhaps, that what sets innovators apart from the rest aren't their tools but their creative vision in using those tools and their unrelenting work ethic.



Encouraged, Hevelius set out to improve his observations, building bigger and better telescopes, with an unblinking eye on his most important project — the quest to revise the paltry star catalogs of the era. Star catalogs, Hevelius knew, were an essential tool for astronomers, enabling them to track the changes taking place in constellations — changes that would profoundly challenge the religious dogmas of the day, which depicted the universe as a static starscape laid out by a divine creator a long time ago. At a time when heliocentrism — the knowledge that the earth revolves around the sun, rather than vice-versa as the church claimed — was still a novel and controversial concept, proving that the universe was a dynamic ecosystem of bodies would be a major feat for science. But star maps had to be accurate and precise in order to reveal these changes.

So, in 1641, shortly after his thirtieth birthday, Hevelius began building his rooftop observatory. Three years into his work, the city of Danzig presented him with a gift — an astronomical instrument that had been stored in Danzig armoury for many years, alongside firefighting equipment, the use and worth of which had remained unknown. A six-foot contraption known as an azimuthal quadrant, it had been envisioned by Krüger but remained uncompleted by his death. Once again, Hevelius's mentor was shaping the course of his life, even from the grave — Hevelius completed the instrument, mounted it on his observatory tower, and began making observations with it. With its ability to measure the angular distances between neighbouring stars, it became a key tool in the completion of his stellar catalog. Long before the invention of the meridian circle, Hevelius used his instrument to record coordinates according to what was essentially an equator line. Over the sixteen years that followed, Hevelius expanded his observatory and equipped it with the best instruments he could build or acquire. His became Europe's finest observatory.

But perhaps the most important event in Hevelius's life and career was not one of science but of romance — or, rather, an exquisite fusion of the two. When he was 55, widowed for over a year, Hevelius married a young woman named Elisabeth Koopman, the daughter of an acquaintance of his, a Danzig



Hevelius using the large azimuthal quadrant to log measurements for his fixed-star catalog.



astronomer with admiration and, soon, adoration. A German biography quotes her as exclaiming one night, while looking through Hevelius's telescope:

*'To remain and gaze here always, to be allowed to explore and proclaim with you the wonder of the heavens; that would make me perfectly happy!'*

It was, essentially, a marriage proposal, which Hevelius gladly accepted. They were wedded at St. Catherine's Church in 1663. Johannes was 52; Elisabeth was 17. Before recoiling in modern judgment, it's important to note that such unions were far from uncommon at the time. But perhaps more importantly, they were often the only way for women, who were barred from most formal education and scholarly work, to gain access to creative and intellectual pursuits through a kind of conjugal apprenticeship.

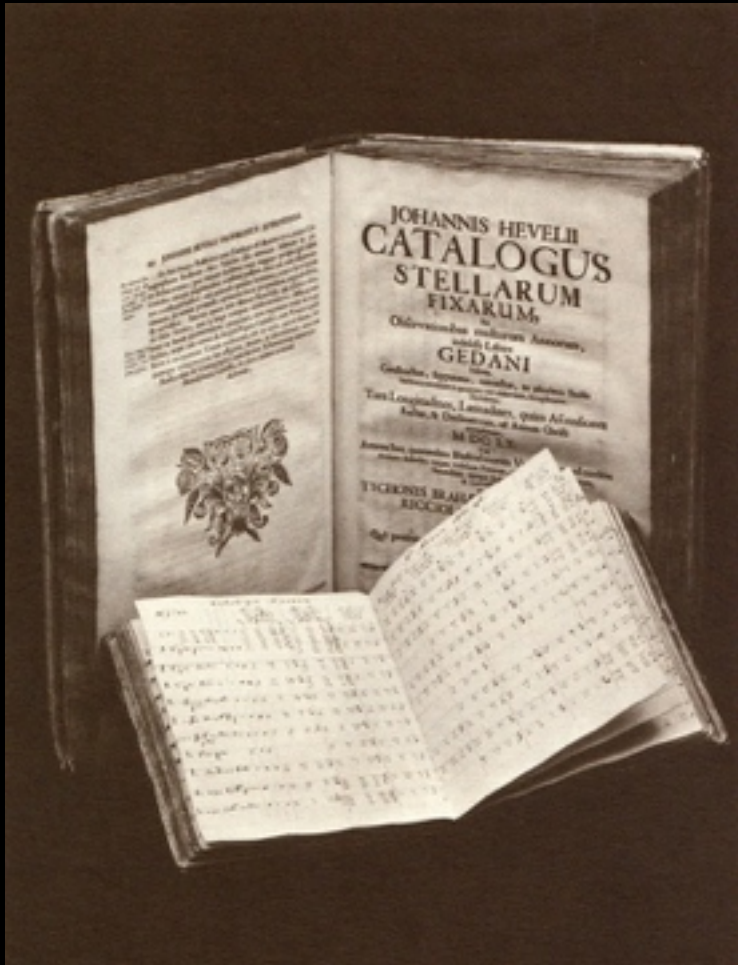
That is precisely what young Elisabeth, who had developed an active interest in astronomy at an early age, did. Hevelius saw in her a kindred mind, and they began making astronomical observations together as she mastered the craft. Nearly two centuries before Maria Mitchell, Elisabeth Hevelius essentially became the first Western female astronomer. All the while, she emboldened her husband — another biography cites her most frequent words of encouragement to him:

Nothing is sweeter than to know everything, and enthusiasm for all good arts brings, some time or other, excellent rewards.

**One of Hevelius's exquisitely illustrated phases of the moon from 'Selenographia'. One of his first great admirers was the famed English traveler Mundy who, upon seeing the maps, marveled in his diary:**

*'Of the Moone he hath Made above 30 large mappes, prints, or Copper peeces of the Manner of every daies encrease and decrease, deciphering in her land and sea, Mountaines, valleies, Ilands, lakes, etts., making in another little world, giving Names to every part, as wee in a mappe of our world.'*

But the fire that destroyed Hevelius's observatory in 1679 nearly put a halt to his quest to catalog the stars. Desperate to resume his project, Hevelius wrote to French king Louis XIV, one of his longtime patrons, a lyrical and heartfelt plea for financial support. The letter stands as an exquisite exemplar of [the art of asking, as well as the curious testament to how deeply religious piety permeated the minds of even the most dedicated scientists of the time:](#)



Most Illustrious and mightiest King, most beneficent Lord: Your high Favour and incomparable Mercy have ever spurred me to scatter with diligence the Seeds of my Gratitude and to sow them in the Bosom of Urania, so that I have set in the Heavens nigh to seven hundred Stars which were not there aforesometimes, and have named some of them after your Majesty. . .

But, alas, will this Fruit of the Labours of mine Age ever see the Light of Day? For no man knoweth what the Dark of Even bringeth. Woe and alas, how multitudinous the Misfortunes that embroil the Life of Man. All my worldly Goods and Hopes have been overturned in the Space of scarce an Hour

Rumour of the dread Conflagration which hath destroyed my astronomical Tower hath no doubt already sped upon rapid Feet to Paris. Now I come myself hasting to Your Majesty as Herald of this great Woe, clad in Sackcloth and Ashes, deep distressed by this Visitation from Him Who judgeth all Things.

May the Windows of the Human Soul never again look upon such a conflagration as devoured my three Houses... if God had not commanded the Wind to turn in its Course, all of the Old City of Danzig would surely have burned to the Ground... Saved by God's Mercy were .. Kepler's immortal Works, which I purchased from his Son, my Catalogue of Stars, my New and Improved celestial Globe, and the thirteen Volumes of my Correspondence with learned Men and the Crowned Head of all Lands.

But the cruel Flames have consumed all the Machines and Instruments conceived by long Study and constructed, alas, at such great Cost, Consumed also the Printing Press with Letters ... consumed, finally my Fortune and the means which God's Mercy had granted me to serve the Royal Science.

If such Damage should crush me to the Ground, I whose Locks are Hoary and who am not far from my Appointed End, could any reasonable Man cast Blame upon me therefor? Yet with the Aid of my many Friends I hope that I may restore my Specula observatoria.

I implore you, Most Illustrious Monarch who has so often manifested Royal Munificence toward me, to breathe by some further Token of your Generosity new Life into the Work which may still lie before me. Then will I no longer bewail my cruel Misfortune, and yours, Noble Majesty, will be eternal Fame for all Posterity.



In October of 1681, the French writer Jean-François Regnard visited the newly rebuilt observatory and marveled in his little-known diary not only at Hevelius's prolific writings and his impressive proto-rolodex, but also at his sublime cross-pollination of art and science:

*His works, the number of which exceeds all belief ... are full of plates made with his own hand: he shewed us them all, besides fifteen large volumes, as thick as the Lives of the Saints, full of letters which the most learned men on the whole world had written to him on various subjects.*

Hevelius remained preoccupied with the completion of his catalog of the stars, which had become his most consuming endeavour and his highest hope for legacy. Alas, he never fully attained it — at least not as a sole creator. On January 28, 1687 — the exact date of his 76th birthday — Hevelius died, having outlived the era's life expectancy by decades. But Elisabeth, who had assisted him in the catalog all along, took it upon herself to finish Hevelius's lifelong quest. She completed the book, dedicating it to the generous Polish monarch. The finished catalog included more than 600 new stars that Johannes and Elisabeth had observed, as well as a dozen new constellations, whose names, as given by Hevelius, astronomers still use today.

Elisabeth guarded the manuscript carefully until her death in 1693, at the age of 46. She left to each of her three daughters a complete set of Hevelius's published works. The eldest, Katharina — who as a teenager had saved her father's star catalog from the fateful fire — fittingly inherited a beautifully illuminated copy of the book, originally prepared as a gift for Louis XIV. But once Katharina married, her husband sold most of Hevelius's prized books to a museum in Russia. The manuscript of the star catalog that had survived the fire was overlooked. Ironically, the greedy son-in-law didn't think Hevelius's magnum opus valuable enough to sell.

**Hevelius and Elisabeth observing with their six-foot brass sextant. In a symbiosis reminiscent of William and Caroline Herschel, he observed, she recorded.**

## Happy ending to a long lineage of near catastrophes

The story of the star catalog and its miraculous survival doesn't end there: In 1734, during the Saxonian-Russian siege of Danzig, artillery fire struck the son-in-law's house and destroyed most of the property. One bomb fell directly into the room where Hevelius's manuscripts and instruments were kept, destroying nearly all unbound manuscripts. But the star catalog somehow survived once more. Over the next two centuries, it made its way to the Danzig Institute of Technology. Then, as World War II broke out, the German administration evacuated the Institute's library to a nearby village, where it was almost completely destroyed in the last days of the war. And yet the star catalog, by yet another stroke of mysterious fortune, survived its third assault by fire.

This veritable phoenix of science finally arrived at Brigham Young University in 1971, where it has remained safe from fire and brimstone in the decades since.

Hevelius devoted most of his effort into perfecting the art of accurate depiction. None of his moon maps made an effort to name the features that he drew. The naming system so familiar to us today — Plato, Tycho, Mare Serenitatus, etc. — would not be developed for another half-century,

*Plafis Line, ab Oppositione recentis.  
Observata, in 2<sup>a</sup> parte II, circa limit A.  
C. HEVELIUS.*

*Anno Christi 1643, Die 26 Novemb. hora 11 i merid. nom. ab  
Oppositione vero 6, Divi 2 Current.*



22.

*Aut. Sculp.*

You can be the first in your community to have a genuine Hevelius antique astronomical souvenir in your home.

This shower curtain is available in bath & bedroom accoutrement boutiques in Hevelius's natal city, Gdansk, Poland.

Visa and Mastercard accepted.



# How the Moon map got those names



This 1707 map was prepared by the Nuremberg cartographer Johann Baptist Homann to illustrate the competing moon nomenclature systems promoted by Hevelius in his 1647 *Selenographia*, and by Giovanni Battista Riccioli in his *Almagestum novum*, published in Bologna just four years later.

Hevelius's nomenclature system was based on terrestrial features, and most of the craters on his maps and drawings were not named at all.

The Riccioli moon map is important because it set forth the lunar nomenclature conventions that we still use.

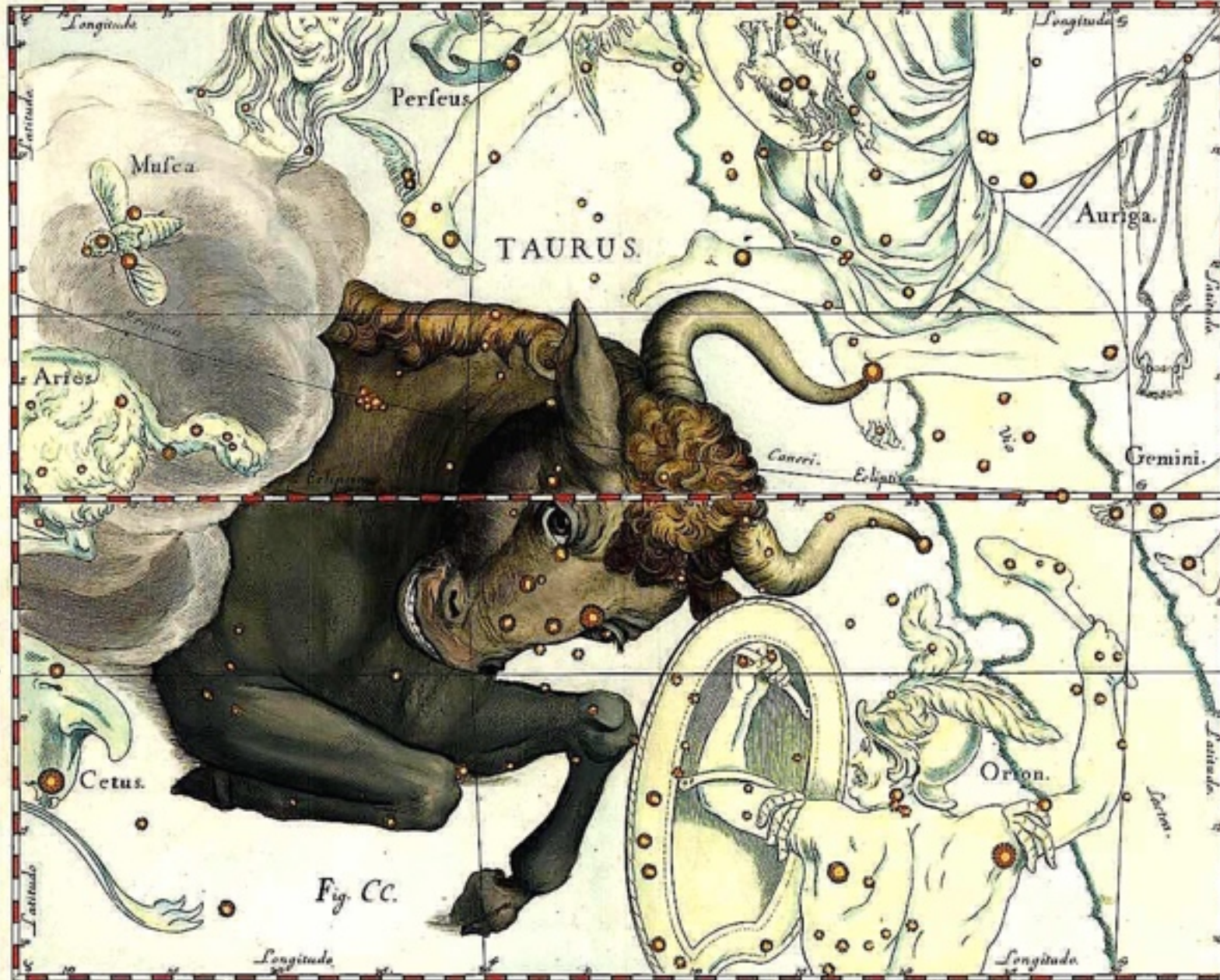
An optician named Francesco Grimaldi with an interest in the moon and planets foresaw the need for a systematic, all-embracing naming convention. He asked his Jesuit colleague Riccioli to devise a naming system for the larger craters and basins.

Thus the larger dark basins (which we now know to be lava flows) received names based on human emotions. e.g., Mare Tranquillitatis meant 'The Sea of Tranquility'. The lunar craters were named after philosophers and astronomers, e.g., Plato, Ptolemaeus, Copernicus, Tycho, etc.

Riccioli's efforts expanded into a full-length book in which this map appeared as the main illustration. The lengthy commentary beneath the two maps and their naming systems suggests that the larger map was designed to be reproduced multiple times over the years and sold as a stand-alone map for casual observers.

The map was printed by the most renowned map maker of the era, Johann Homann, in Nuremberg. Initially Homann was not all that interested in astronomy until commissioned to print this map. He knew opportunity when he saw it and went on to be the re-eminent celestial cartographer of his time.

# The most dramatic of the early star atlases



The lofty level that the art of engraving on copper plates had achieved in its first two centuries is beautifully exemplified in the following images taken from Johannes Hevelius's *Firmamentum Sobiescianum*. The plates were based on Hevelius's laboriously logged *Catalogus Stellarum Fixarum* of star positions and brightnesses. The *Catalogus Stellarum* was published as a companion volume to the double-folio (38 x 33 cm) volume of 54 engraved plates. Here we reproduce ten of the most striking.

Hevelius was the most diligent observational astronomer of the last half of the seventeenth century. His star atlas is notable for many reasons. It contains fifty-six large, exquisite, double-page engraved star maps, each based upon drawings by the famous Polish artist Andreas Stech, who was also living and working in Gdansk (today Danzig) at the end of the 17th Century.

The result was the first star atlas to rival Johannes Bayer's *Uranometria* in accuracy, utility, and influence. It is unique among the Grand Atlases of the seventeenth century because it depicted the constellations as they would appear on a globe, that is, from the outside looking in, rather than from the ground looking up. That is why Orion's belt stars swoop down to the right, rather than to the left.



# Hevelius's Firmamentum Sobiescianum

Dana De Zoysa

It was no easy process to accurately render Hevelius's long lists of handwritten tabular data into an atlas characterised by minimal text and maximal image. These engravings are more complex both mathematically and artistically than they seem at first glance.

The star positions for the charts were extracted from Hevelius's star catalogue, which was based on his own observations with a quadrant or sextant, as we saw above. The *Catalogus Stellarum Fixarum* shown on page XX above was also first published along with this atlas.

Copperplate engravers didn't just start at the top left and work down. The tabular positions were first drawn on sheets of paper roughly resembling the finished engraving in size. The first item to be sketched was the thin hatched border around the edge. The hatches are graduated in actual sky degrees in latitude. But the longitudinal graduations are a repeating cycle of 30 arcminutes with each hatchwork rectangle corresponding to one arcminute,

The cartoon artist (Andreas Stech in this case) would then carefully place each star position using rulers and dividing callipers.





At first the star positions plotted using small pencil or charcoal dots. The paper maquette was measured, checked, and cross-checked using calliper dividers and rulers.

The paper was then placed on top of a freshly smoothed and polished plate of copper-tin-lead alloy sized (in the case of celestial and terrestrial charts) to a standard 29 x 34 cm landscape shape. That size left a border of 2 cm on all sides to nearly fill the 33 x 38 cm standard double folio paper size used at the time. The plates were roughly 4 to 6 mm thick so they could be incised rather deeply if necessary and also remain rigid during the ink-transfer pressure imposed by the printing rollers of the time.

The star positions were then stamped into the copper plate, each star sized according to its visual brightness in the sky. Closely examine the 1st and 2nd magnitude stars on these plates and they look like tiny rosettes, all identical in their number of points and pattern. These were made using hammer-forged steel dies, one for each star magnitude from -1 to mag 5 or 6. The dies were impressed into the plate with a light tap. This was a job for the master engraver, for it took years of practice to learn the exact amount of tap the individual copper sheets required. Since it was so easy to overdo it on the tapping

pressure, engravers made several light taps till the look-&-feel of the final dent into the copper was right.

Once all the stars and coordinate lines had been transferred, the figures were engraved directly onto the plate without a paper pattern. This is where the master engraver Andreus Stech's artistic skills came to the fore. The first half of his talent was technical: the intaglio ("cut in") process depended on ink filling tiny grooves in the copper, which then transferred to a sheet of paper under the pressure of the printing press roller. The steel dies used to perform the cutting were called burins. These were very sharp vee-shaped chisels with a wide, rounded handle to fit the palm. They were designed to be pushed forward into the copper sheet, not pulled into it. The engraver had to be very sure of the line he wanted to draw. ("He" because the closed-shop guild rules of the time forbade women.) It took years, if not decades, of experience to build the skills required to free-hand incise a set of images like the one to the right.

Still, all was not lost if the engraver erred in his judgment of the line's depth and curve. The specific proportions of copper and tin in a printing plate had been refined over the years to accommodate the fact that mistakes are inevitable. All the engraver needed do was to smooth the plate with soft soapstone and a moistened finger, then re-cut the line.





Once the exacting work of cutting the copperplate was complete, the rest of the printing process in Hevelius's 17th century Europe was an achieved science, i.e., a technology whose major advances had been made and codified into an established craft serving commerce instead of seeking new knowledge. Although woodcut images predated engraving by two centuries, their chunky depictions and brief working life rendered them obsolete as soon as a better technology came along.

Engraving itself was not the better technology — it had been around for well over a thousand years in the form of engraved gemstones and metal artefacts for the luxury market. Rather, the flat copper plate suitable for volume printing was the better technology. Once the sheet was incised with an image, it could be placed into a traditional flatbed-&-roller printing press and reproduced up to 200 times before the natural abrasiveness of paper wore the lines too thin. It would then be re-incised with new lines more or less exactly following the originals.

“More” often meant “less” by this time, because the purity of the lines was lost. For this reason, in the antiquarian print and old map trade, first-run works are called “first strike” while images printed from re-incised plates are called “restrike” or “second strike”. The reputations of numerous famous artists — Rembrandt being an example — were sullied by

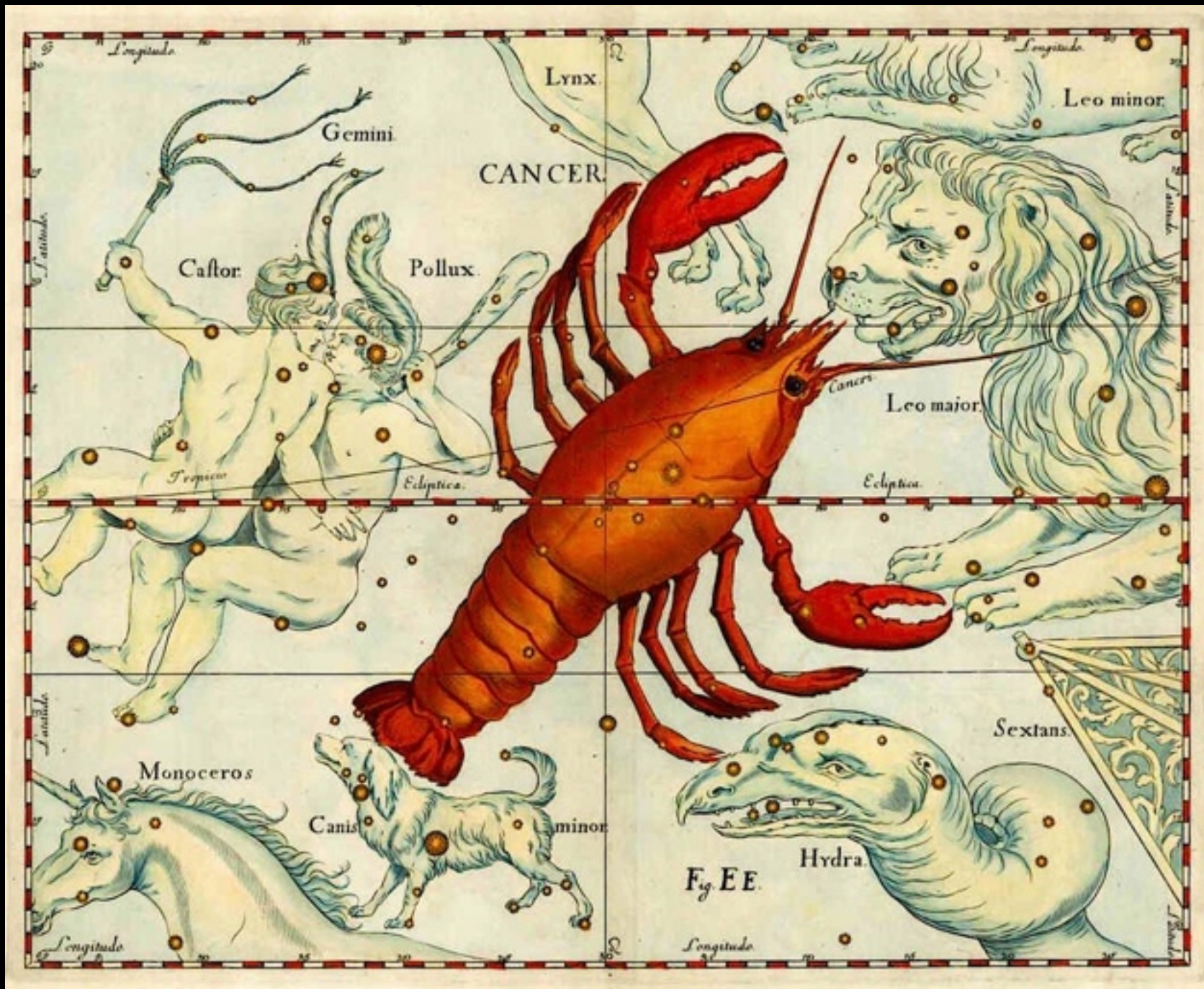
unscrupulous printers who would shelve the original plates of commercially successful works, wait for the artist to die or lose popularity, then run off second strikes to sell as originals till the quality was so poor even newbie collectors could spot them. Check out the thumbnail ads in the backpages in an art magazine for an amusing education. Just don't let them near your wallet.

Intaglio (aka gravure) printing fell out of favour with the introduction of photo-offset printing in the late 19th century. Today the only products regularly created with 17th-century style intaglio printing are postage stamps and printed bank notes.

It is easy, as we marvel at the beauty of the Hevelius charts, to overlook the enormous impact that their underlying technology exerted on thinking of that era — even up to our emotionally gaudy but intellectually impoverished Twitterverse today.

One of print's least-heralded boons to humankind was that ideas could not be lost any more, either lost intentionally by proprietorial knowledge factories like religious doctrine, or lost by neglect, as in the case of the truth in the hands of politicians.





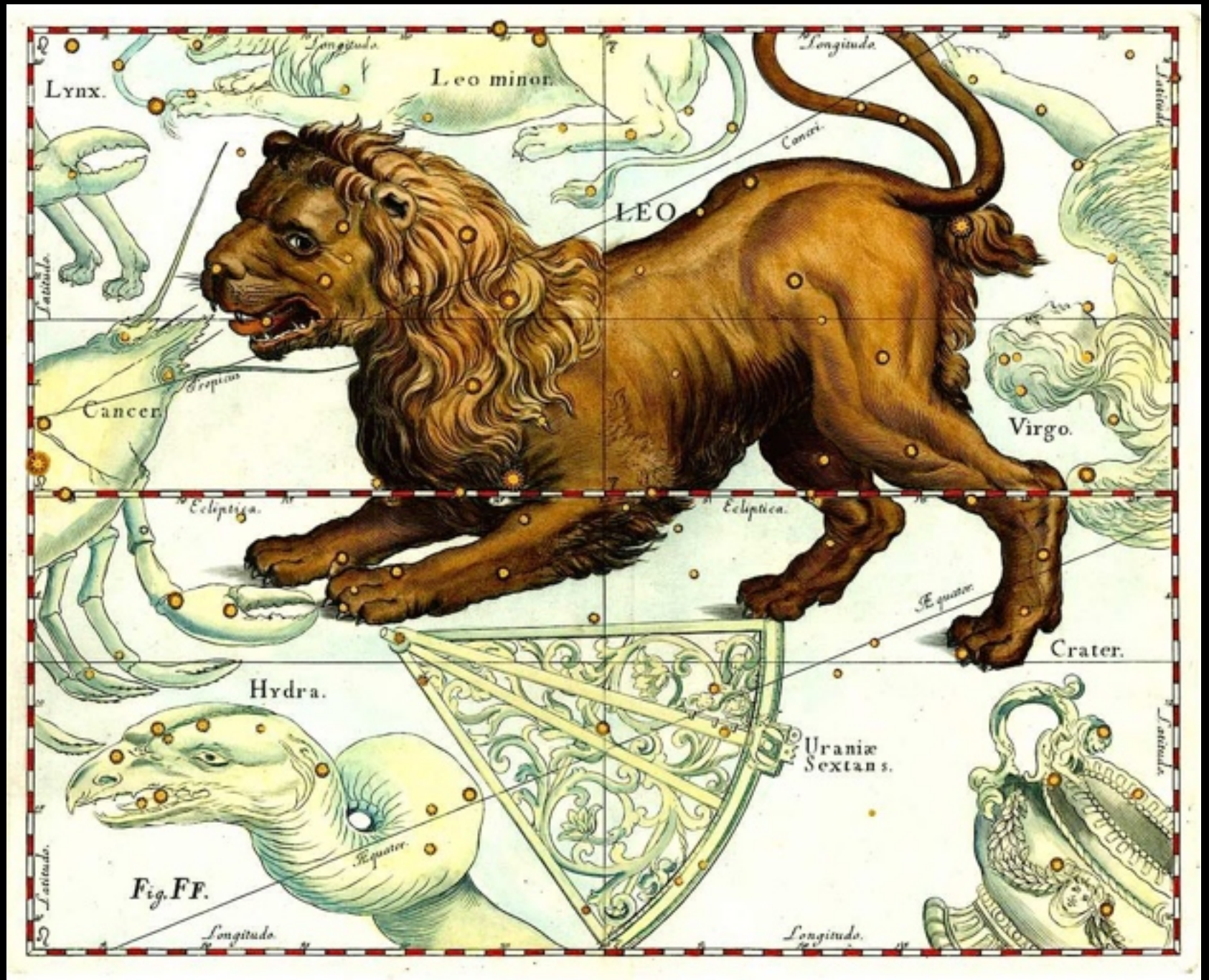
Johannes Hevelius was one of the pre-eminent observational astronomers of the seventeenth century. He lived through the era of a pivotal split between the dominance of theoretical astronomers (i.e., astrologers) and observational astronomers. Hevelius belonged to an esteemed college indeed — Tycho Brahe, Galileo Galilei, Johannes Kepler, Pierre Gasendi, Domenico Cassini, Christopher Huygens, Isaac Newton, and Edmund Halley. It must be conceded that a number of these early pioneers in astronomical science were not above putting a loaf of bread on the table by advising the wealthy whether the planets were aligned in favour of a prospective spousal contract or war on an inconvenient neighbour. The presence of Venus in Cancer (see left) for example, would suggest that a prospective domestic partner with good credentials in the culinary and dustmop arts was also unsullied by the prior attentions of other men.

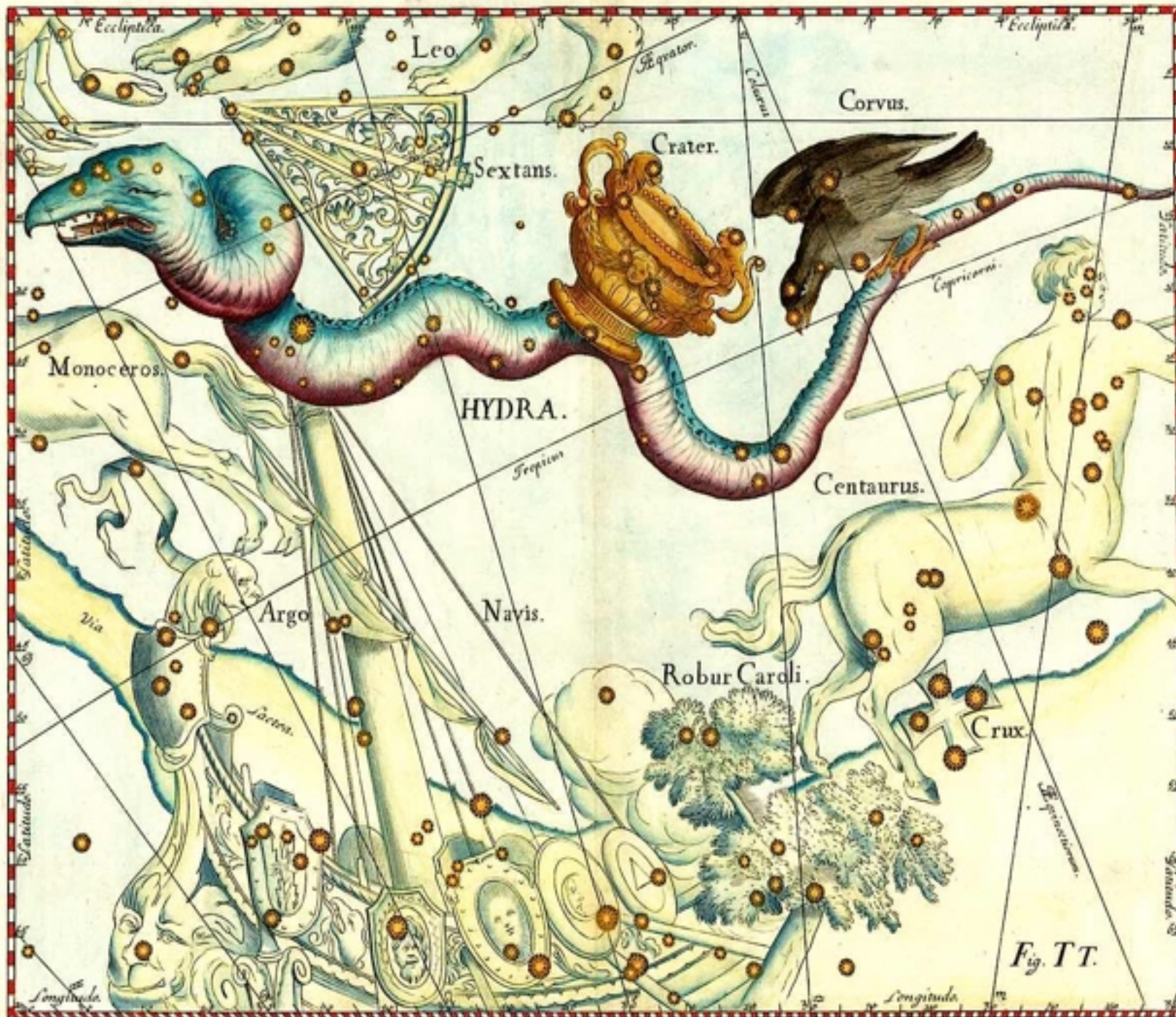
It can be averred that observational precision of the type introduced by Hevelius and his colleagues changed the course of theoretical astronomy. They introduced maths and the intellectual journal. They moved the wellspring of authority out of the chapel and court into the countryside and the sky. Up to the middle of the 17th century, astronomers worked mainly at court. The patronage of a ruler enabled them to advance their careers, but at the cost of casting horoscopes.

Hevelius was free of that. He was as competent a beer brewer as he was astronomer. He owed his financial independence and thus his ability to conduct unhampered astronomical research, to the family breweries established by his father. Before the inspiration to undertake a precise catalogue of star positions, he dabbled a bit in art, served as a Gdansk city councillor, learned how to draw and then the far more exacting task of engraving, passed through a phase of art collecting and patronage, and served as a Lutheran pastor.

Hevelius received his intellectual grounding at the renowned university-level Academic Gymnasium in Gdansk. He was a pupil of Peter Kruger, who corresponded with Johannes Kepler, Tycho Brahe, and Pierre Gassendi, and introduced astronomical research into Gdansk.

Hevelius then went on a three-year tour of the Netherlands, France, and England, during which he met the scholars with whom he corresponded for the rest of his life. Some in turn visited Hevelius's observatory in Gdansk. His wealth allowed him to build, starting in 1641, the previously mentioned observatory. He constructed his own elaborate and fussily decorated sextants. Some were so





good a machinist that he he made copies for others as an income producer. He started his own print shop in which he published beautifully illustrated catalogs of his observations. Alas for him, Hevelius didn't heed the Number One rule made possible by print: store backup copies somewhere else. When his observatory burned to the ground in September 1679, he lost every single manuscript and printed copy of all the observations he had made save for one single book rescued by his daughter, the *Catalogus Stellarum Fixarum*.

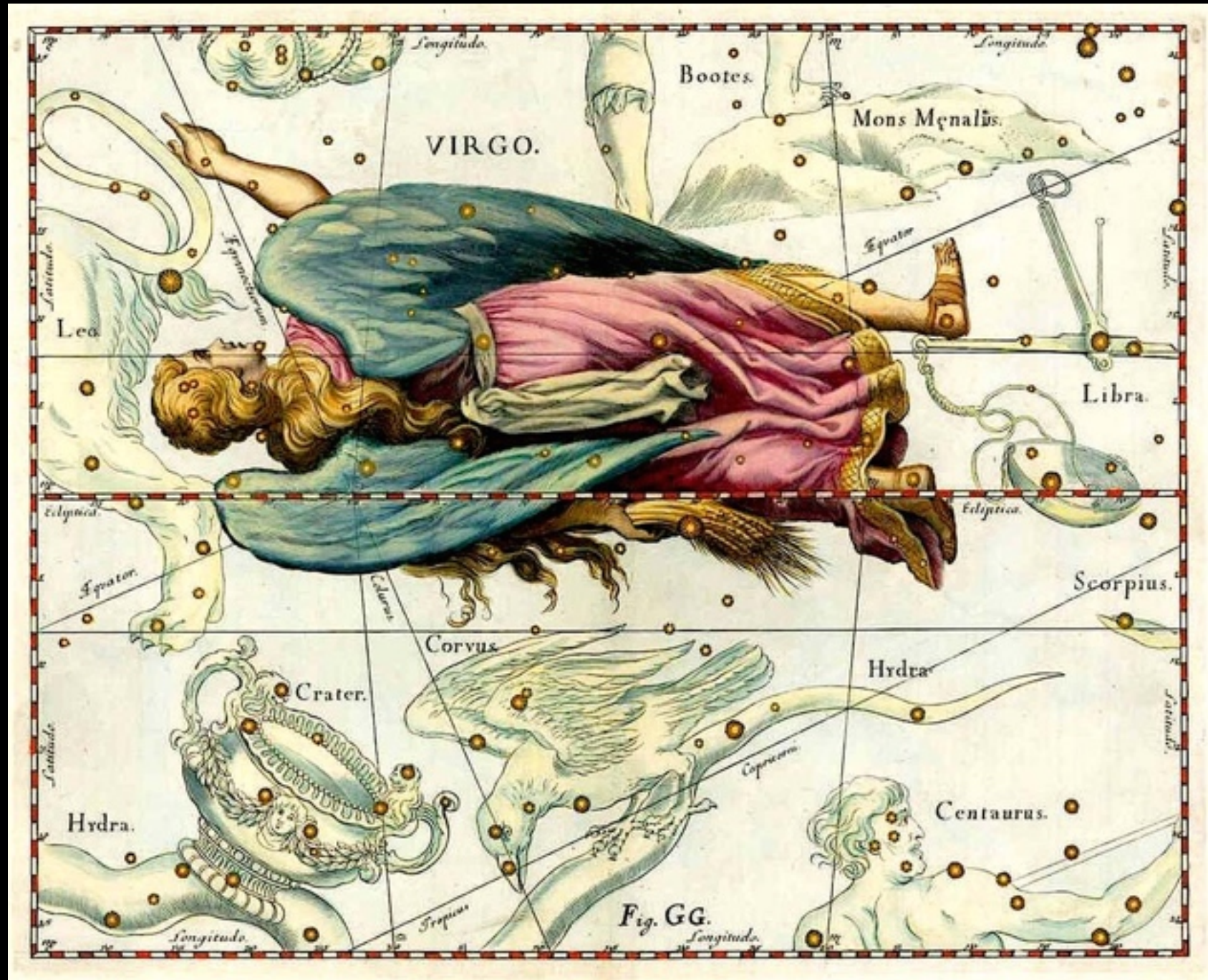
Luckily for him, and for us today, his reputation as an astronomer ahead of his time and his voluminous correspondence had brought him to the attention, and thus the patronage, of the most powerful patron in the world at the time, King Louis XIV. A single letter from Hevelius to Louis XIV earned him enough patronage to rebuild everything.

Hevelius never fawned in a princeling's court. He passed his evenings not hatching plots in courtier cabals, but his own observatory with his wife Elisabeth at his side. He was invited to the courts of the Brandenburg elector Frederick William, Christina, Queen of Sweden, and Charles II, King of England. He astutely scheduled these invitations for the interminable Poland winters when observation was genuinely unhealthy.



Hevelius was famously disdainful of the academic community and its way of thinking. Instead, he communicated his research via scholarly societies, which, as of the 17th century, had become professional institutions. We do not hear much about the *Journal des Savants* or *Acta Editorum* today, but these and the better-known *Philosophical Transactions* were the foundations on which today's vast professional literature were built. Then, as now, discussions took place concerning concrete facts and rigorous process. They were after science, not philosophy. The most illustrious society of this sort was the *Royal Society of London for the Promotion of Natural Knowledge*, founded in 1660 by Francis Bacon to support empirical research in the natural sciences. Hevelius became a member of this elite circle in 1664.

In the spring of 1679 Hevelius achieved an important scientific success. John Flamsteed and Robert Hooke had been questioning Hevelius' research methods for a long time. Hevelius was quite literally a visual observer — naked eye style. He mistrusted telescopes. Hevelius demanded arbitration from the Royal Society. They sent 23-year-old Edmund Halley to Gdansk to compare Hevelius's observations with Halley's latest equipment. After more than a month of joint effort Halley confirmed the accuracy of





Hevelius's measurements. At the time Hevelius was 68 years old. On departing from Gdansk, Halley presented Hevelius with a letter testifying to the positive results of their work and the precision of Hevelius's methods and results. It was an unequivocal affirmation Hevelius's accuracy as a naked eye observer.

Hevelius was indeed one of the most eminent scholars in the world. His record is immense. He made observations of sunspots, 1642-1645. He discovered four comets, in 1652, 1661 (probably Ikeya-Zhang), 1672 and 1677. He devoted four years to charting the lunar surface, discovered the Moon's libration in longitude, and published his *Selenographia, sive Lunae descriptio* in 1647.

If we call Hevelius, "the founder of lunar topography," it is an acknowledgment well earned and well regarded.

**Now take a break  
and marvel at the  
wondrous results  
of all of the above.**

**Click on the large text, or here.**



# Astronomical Society of Southern Africa



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